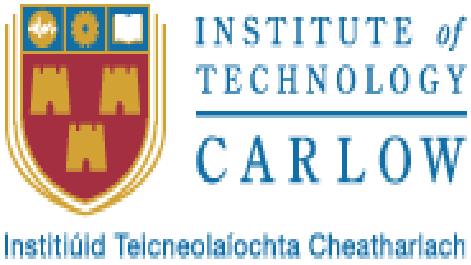


# Bachelor Of Science (Honours)

# Software Development

## Home Automation System Research

**Course Code: CW238**

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Submission Date: 1 November 2019

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# 1. Motivation

The birth of the first steam engine in the 18th century marked the beginning of human activities into the Industrial 1.0 era. The use of electric energy in the 19th century was the symbol of Industry 2.0, and the information age of the industry in the 20th century.

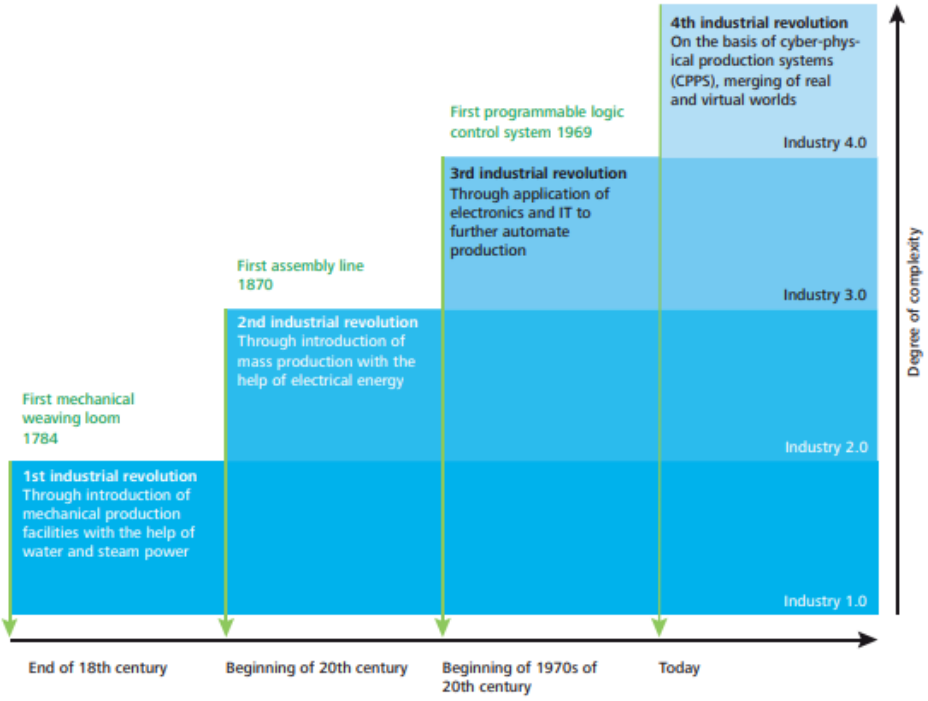


*Figure 1 Definition of industry 4.0.*
*Source: Schlaepfer, R. C. and Koch, M. (2014) Industry 4.0 Challenges and solutions for the digital transformation and use of exponential technologies, Deloitte. p3*

It has been more than 70 years since the birth of the first computer, and the publication of Moore's Law has been more than 50 years. From the original giant machine used in the military field, the computer can now be as small as a button size and can be applied to various fields using small smart sensor devices. Coupled with the booming of the Internet over the past 20 years, people have used the computer and Internet for information collection, processing, and sharing. The Internet of Things has gradually transitioned to the Internet of Things era that uses small electronic sensing devices to automatically collect environmental data for analysis. With the ultra-high bandwidth of 5G (The fifth-generation cellular network technology), the application of ultra-low latency and other technologies will promote the popularity of the Internet of Things to various fields, which means that we are about to enter the era of Industry 4.0.

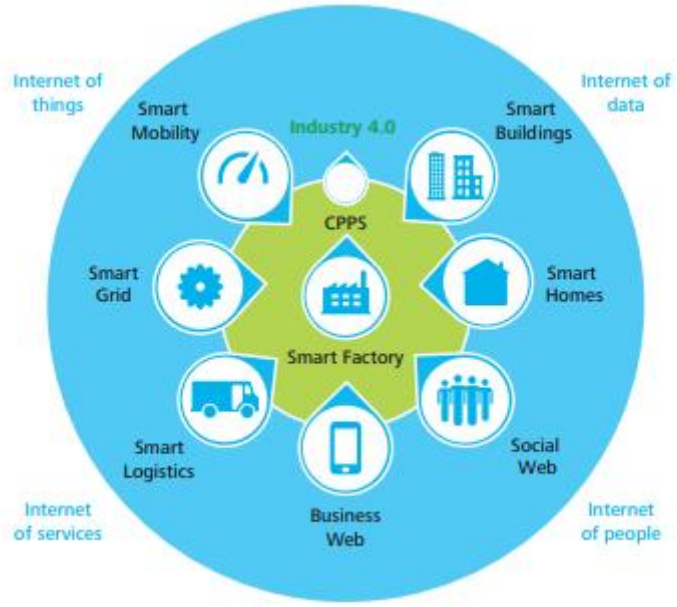


*Figure 2 The industry 4.0 environment*
*Source: Schlaepfer, R. C. and Koch, M. (2014) Industry 4.0 Challenges and solutions for the digital transformation and use of exponential technologies, Deloitte. p4*

As indicated in the IoT report published by ITU(International Telecommunication Union) 2012, *"The IoT is expected to greatly integrate leading technologies, such as technologies related to advanced machine-to-machine communication, autonomic networking, data mining and decision-making, security and privacy protection and cloud computing, with technologies for advanced sensing and actuation.".* As shown in Figure 3, that describe the IoT three dimensions and relationship between them.

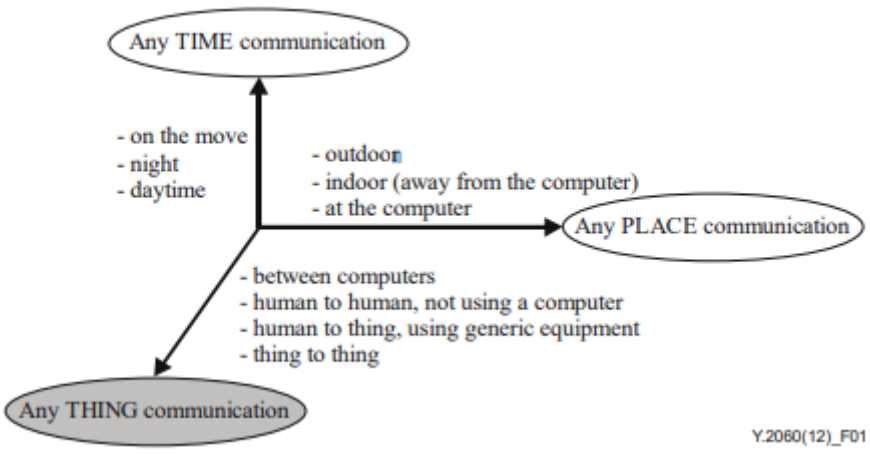


*Figure 3 Three dimensions of IoT*
*Source: ITU-T Y.2060, p3*

In the Internet of Things, objects in the physical world or the information world can be identified and integrated into the communication network, physical devices can be sensed, motivated and connected, while the information world can be stored, processed and accessed. The communication network transmits the data captured by the device to the application and other devices and

transmits the instructions of the application to the device. The communication network also provides reliable and efficient data transmission capabilities.

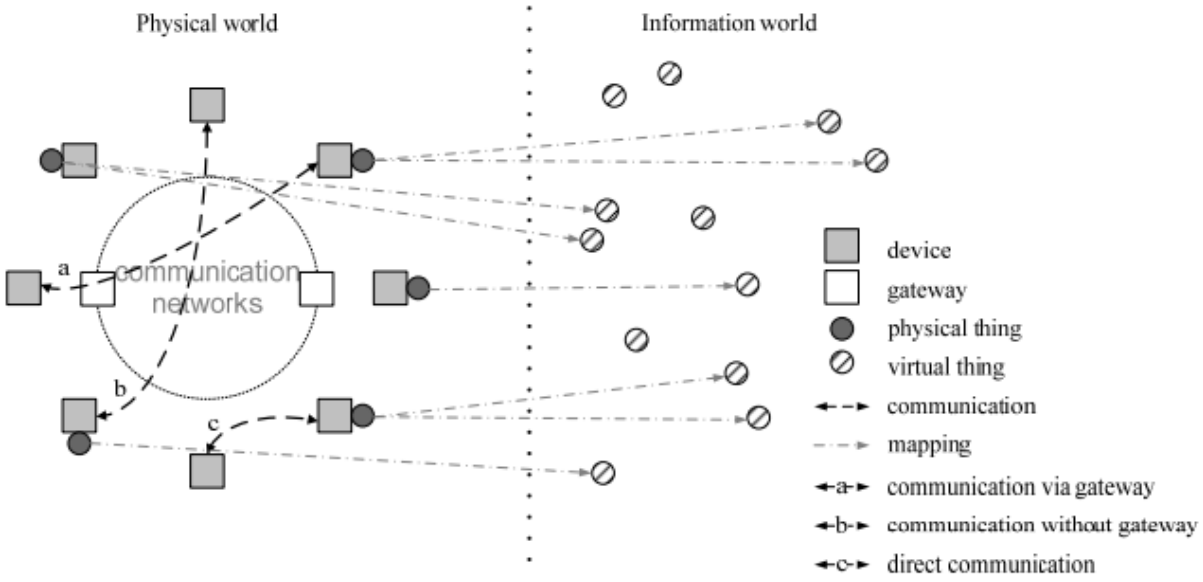


*Figure 4 Technical overview of the IoT*
*Source: ITU-T Y.2060, p3*

There is a very important application of IoT in real world is Home Automation. It is a house or living environment that contains a collection of different types of sensors to allow automatic or remote control of home devices and systems. It can provide comfort, Leisure, safety, entertainment, energy, etc. Therefore, Home Automation would improve people's living standards. The concept of smart home is closely related to the field of Smart Home, so it also known as Smart Home.


*Figure 5 Overview of the Home Automation*
*Source: Stories by Williams. (2014). The Future of Smart Living: Smart Homes.*

## 2. Research Method

i. Research on the home automation industry from different perspective:
   - Marketing Analytics
   - IoT Technologies Evolvement
   - Home automation Research
   - Home Automation System Case Study
   - Security & Privacy

ii. Obtain home automation industry information in different ways:
   - Internet Resources
   - College Library Books
   - Industrial Report
   - International Standards Organization Literature
   - National Development Policies & Planning

iii. Eventually, the valuable information is written into a report:
   - Periodic discussion with the supervisor
   - Information is aggregated into reports
   - Review report and submission

## 3. Research Scope

The research scope of the report will cover the following topics:

- Home Automation Technologies
- Algorithm Research
- International Standards
- Networking Communication Protocols
- Security and Privacy Protect
- Industry Applications & Solutions

## 4. Marketing Analytics

According to a website which called *Statista* indicate, overall consumer electronics generated US$997 billion in revenues worldwide in 2018, and by 2023, this is forecast to rise to US$1,113 billion. The consumer electronics market is driven by constant innovations and transformations.

Especially, home automation market also has huge changes, according to the data from *Statista* indicates the revenue of the home automation market amounts has already US$23,577 million in 2019 and the market expectation on revenue growth will reach 17.3% in 2020.

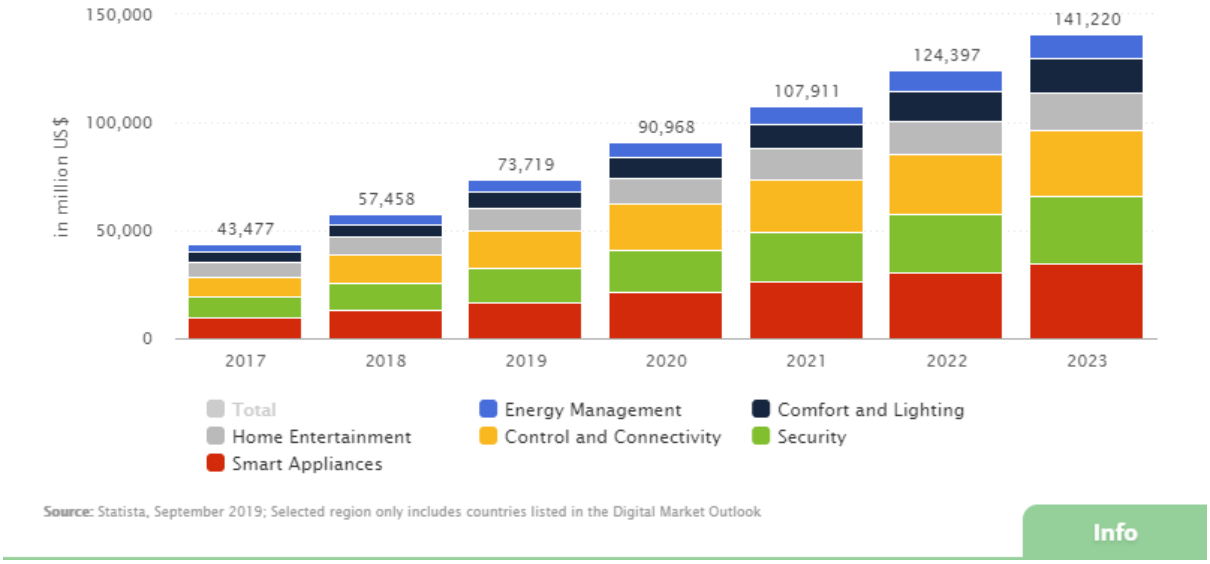


*Figure 6 Smart home revenue*
*Source: Statista. (2019). Smart Home - worldwide | Statista Market Forecast.*

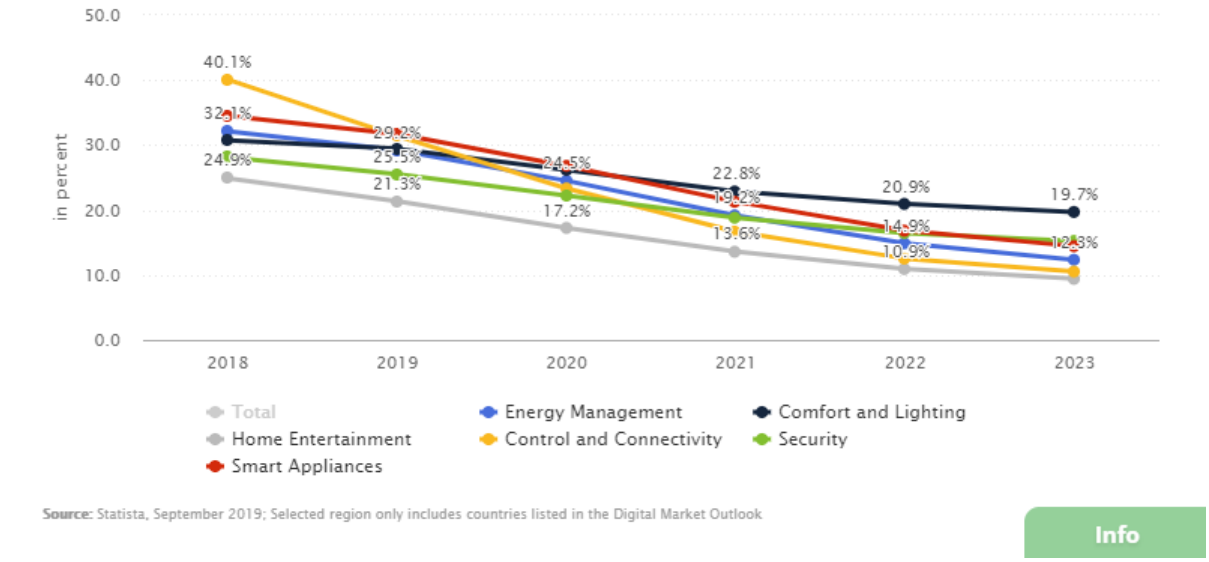


*Figure 7 Smart home revenue growth expectation*
*Source: Statista. (2019). Smart Home - worldwide | Statista Market Forecast.*

Global home automation industry comparison, the market volume biggest and most revenue is United States, and China follows United States. But on another hand, the household penetration rate that was accounted for the vast majority by United States and Europe.

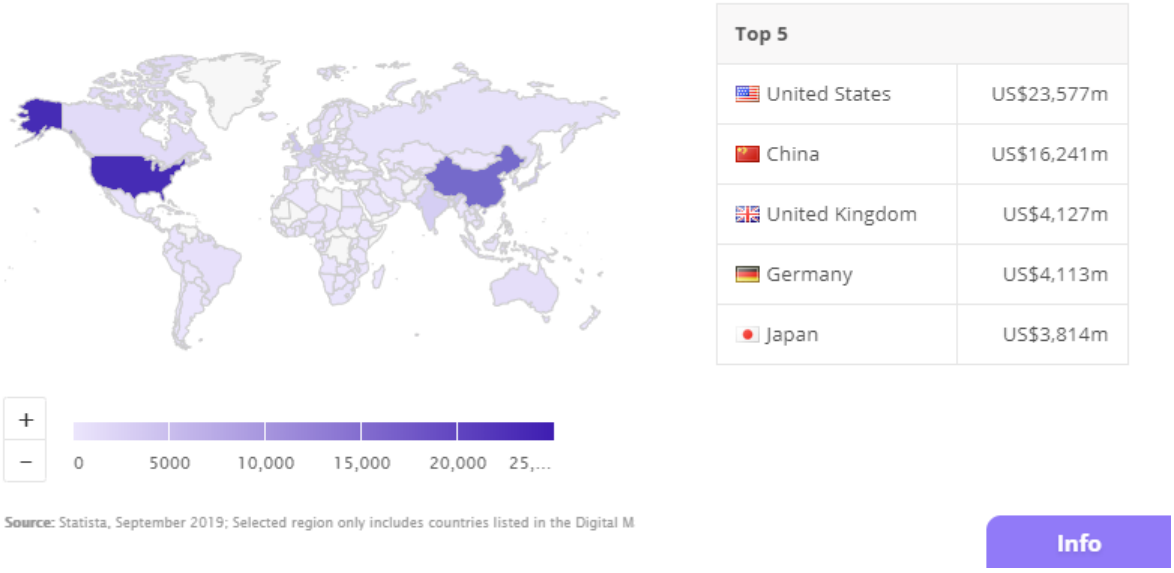


*Figure 8 Global Comparison for Revenue*
*Source: Statista. (2019). Smart Home - worldwide | Statista Market Forecast.*

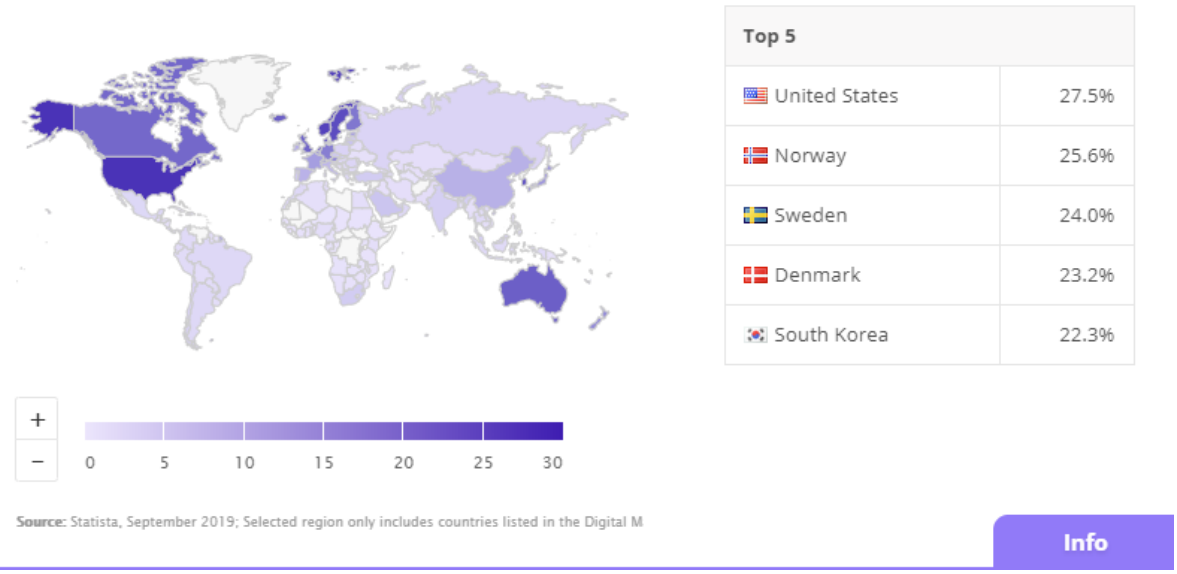


*Figure 9 Global Comparison for Household Penetration*
*Source: Statista. (2019). Smart Home - worldwide | Statista Market Forecast.*

## 5. Technologies Evolvement

An overview of home automation related technologies will be in this section. These technologies current comprehensively were applied in IoT industry.

## 5.1. Networks

In the home automation field, we need to design and plan the network according to actual needs. Next, we will examine several common network types.

### 5.1.1. Wi-Fi

Wireless LANs are becoming more and more popular, and the network infrastructure that is commonly found in public places such as homes, schools, office, airports, and cafes. It can be used to form a local area network and connect to a local network via a smartphone, tablet or notebook.

Wireless LANs mainly use the 802.11 standard protocol. The standard defines services, clients, access points, and the networks that connect them to a standard-compliant wireless LAN. As it continues to update, different versions are derived: 802.11/802.11a/802.11b/802.11g/802.11n. There are mainly differences in operating frequencies and differences in transmission rates between them. The current widely used version is 802.11n, which uses MIMO (Multiple Input/Multiple Out) technology and wider radio frequency channel. It takes advantage of frame aggregation technology to decrease time between transmissions. so, it has 600 Mbps rate in transformation.

The 802.11 protocol provides the following standard services:

1. Association
2. Re-association
3. Wired equivalent Hemi WEP
4. Distribution service
5. Data transfer
6. Privacy protection mechanism
7. QoS traffic scheduling
8. Transmission power control
9. Dynamic frequency control

### 5.1.2. Bluetooth

Bluetooth is a wireless LAN standard that can be used to connect computing devices, communication devices, and nearby short-range devices, low-power, low-cost radio connections in a master-slave mode using the Pairing method. It is a low-power system charger with a range of 10M and operates at 2.4GHz with a maximum allowable number of 8 nodes.

Therefore, the shortcoming based on Bluetooth network communication technology also very obvious. It is limited by the distance factor and the maximum allowed connection nodes.

### 5.1.3. Z-Wave

Z-Wave is a wireless LAN networking technology led and developed by a Danish company called zensys. This technology has many applications especially in the field of smart home. It features radio frequency, low cost, low power, high reliability, short range wireless communication. The network consisting of Z-Wave has its own independent home address (Home ID), and the address (Node ID) owned by each node device in the network is allocated by the control node device Controller.

Each Z-wave network can accommodate up to 232 slave nodes, and there can be at most one master control node, and other nodes are only used to forward the main control node information.

### 5.1.4. Zigbee

Like Bluetooth and Z-Wave technology, Zigbee is also a wireless LAN protocol for transmitting data at low speed and short distance. The bottom layer uses the IEEE 802.15.4 standard specification and uses the 2.4 GHz band. The main features are low speed, low power consumption, low cost, low latency, support for many online nodes (theoretically support 2 to the 16th power), far more than Bluetooth 8 nodes and Wi-Fi 32 nodes and Z-Wave 232 node. Support multiple network topologies, low complexity, reliability and security.

Compared with the traditional network communication technology, Zigbee carries out the corresponding power required for wireless communication transmission processing to 1MW. If it enters the sleep state, the power required is lower. In terms of security, Zigbee provides a three-level security model, including basic security settings, Access Control List (ACL) and AES128 data encryption standards.

### 5.1.5. RFID & Wireless Sensor Networks

RFID is an acronym for Radio Frequency Identification, a technology that makes things in our daily lives part of a computer network. For example, kittens, puppies, cows or sheep can be tagged with RFID labels to record their activity. An RFID label usually consists of two parts, a unique identifier, and receive an antenna for radio transmission. When an RFID-enabled object enters a range that the RFID reader can recognize, the RFID reader will communicate with the RFID label and obtain information.

Three operating frequencies of RFID:

1. UHF RFID It operates from 902 to 928 MHz and can operate within a few meters. Mainly used on freight pallets and driver's licenses
2. High-frequency RFID It operates at a frequency range of 13.56MHz and can operate within 1 meter. Mainly used in passports, credit cards, books and contactless payment systems
3. Low frequency RFID is mainly used to record the activity track of animals.

The RFID carrying the sensor can be used to monitor migration of migratory birds, volcanic activity, and traces of poultry by constructing a wireless sensor network.

But the unavoidable fact is about the security of RFID. Since the design was originally designed to communicate with the RFID reader at a specific frequency, there is no encryption in the communication process. Undoubtedly this will pose a huge risk to personal privacy.

### 5.1.6. 5G

5G is called the 5th generation mobile network, and it is also the latest generation of cellular mobile communication after 4G, 3G and 2G. The difference between them is mainly reflected in the bandwidth and speed of the transmitted data. It can be very analogous to the 2G for carriage, 3G for trucks, 4G for trains, and 5G for high-speed rails. Their carrying capacity and speed are increasing in order. 5G's performance targets are high speed, very low latency, low power consumption, low cost, high system capacity and large-scale device connectivity.

In theory, the data transmission rate of 5G is 10Gbps for uploading, 20Gbps for downloading, and nearly 100 times faster than 4G. It will provide strong network support for artificial intelligence and the Internet of Things and is the cornerstone of the upcoming Industry 4.0 era. In the current international situation, between the state and the country, there is an intense field of competition between companies and companies.

## 5.2. Communication Protocols

### 5.2.1. HTTP/HTTPS

HTTP is an abbreviation for Hypertext Transfer Protocol that was applied in web application transfer data between client and server. It is an application layer protocol that works on the TCP/IP protocol stack to create a TCP connection that was used to communicate on request and response model. HTTP is a stateless communication protocol which taken advantage of by RESTful API.

The RESTful API is an architectural style that defined each URI which uniquely points operation of a resource through a specific HTTP request method, such as PUT, POST, DELETE, GET, PATCH, etc. RESTful API was comprehensively applied in the distributed web application and cloud services, it can decouple the dependency between modules.

HTTP is not a secure communication protocol because it used the way of plain text to transfer the data between the client and the server. HTTPS is the same as HTTP except it takes advantage of a way of asymmetric encryption to transfer data.

### 5.2.2. WebSocket

The WebSocket also a protocol works on top of the 4$^{th}$ layer of the OSI reference model that allows full-duplex communication. It can send a polling request within the client and wait until the response was returned by the server.

There are two types of polling operations, short polling, and long polling. The short polling would launch a request within the client then obtain the response immediately even though nothing was returned by the server. The long polling that also would launch a request within the client but only the data was returned by the server then just releases the connection, otherwise, the connection will keep until a timeout was reached.

Obviously, the long polling more saves bandwidth than short polling if the data produced infrequently by server.

### 5.2.3. MQTT

MQTT is an abbreviation for Message Queuing Telemetry Transport. It was developed as Pub/Sub architecture message queuing service by IBM used to IoT communication between devices. It works on where is required or the network bandwidth is limited. There are two components, the broker, and the client within MQTT. The client is either a publisher or subscriber. The broker receives the data from the publisher, transfer data to the interested subscribers who subscribe to the topic.

The diagram below clearly shows how the MQTT works.

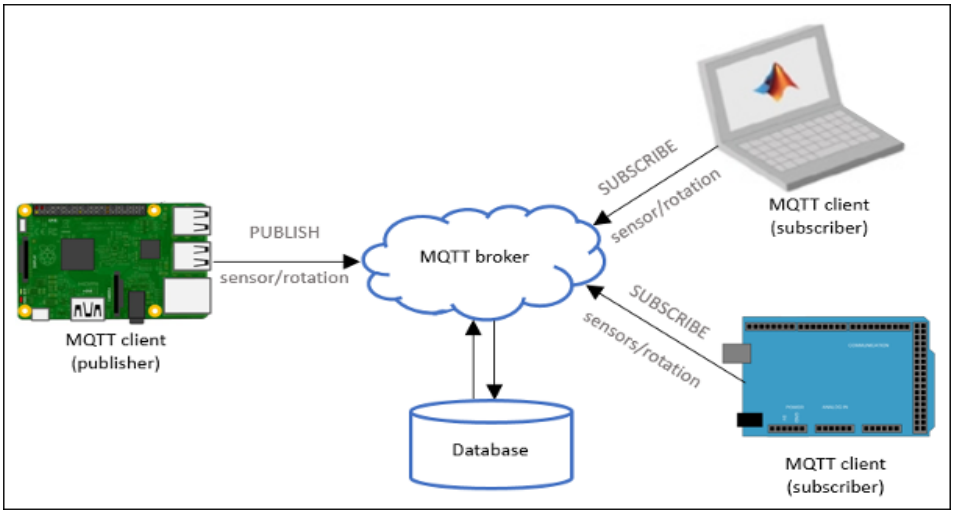


*Figure 10 How does the MQTT works?*
*Source: Mathworks.com. (2019). Publish MQTT Messages and Subscribe to Message Topics- MATLAB & Simulink.*

### 5.2.4. AMQP

AMQP is an abbreviation for Advanced Message Queueing Protocol. It is a message queue middleware. The features of the AMQP are message exchange routing, reliability, and security. It like MQTT but different is that MQTT was designed to lightweight suit for tiny devices. The AMQP was designed to data exchange for high concurrent requests between large-scale distributed systems

## 5.3. MEMS

MEMS is an abbreviation for Micro Electromechanical System. Using traditional semiconductor processes and materials, it integrates sensors, actuators, mechanical mechanisms, signal processing and control circuits, interfaces, communications and power supplies into one micro device. It has the characteristics of small size, low cost and high integration. It mainly includes the following categories: MEMS physical sensors, MEMS environmental sensors, MEMS bio sensors, etc. In the Internet of Things, there will be thousands of MEMS tiny devices integrated. Therefore, MEMS that is one of critical technologies in IoT field.

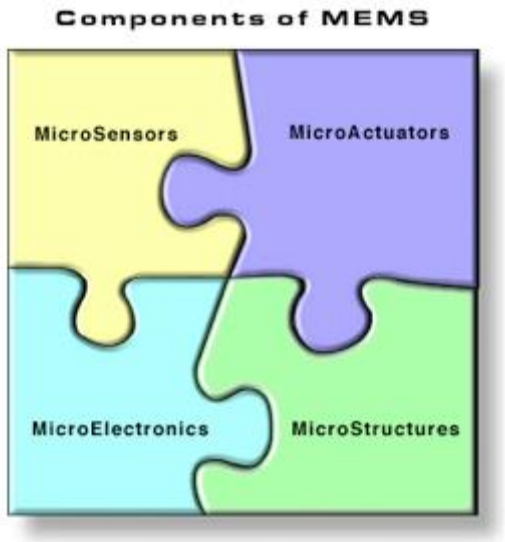

*Figure 11 Components of MEMS*
*Source: Tes Teach with Blend space. (2019). Chapter 7 Mems Technology - Lessons - Tes Teach.*

We can just like playing a jigsaw puzzle to integrating different MEMS devices into one system to serve Home automation.


*Figure 12 MEMS Samples*
*Source: Bosch-sensortec.com. (2019). IoT and Smart Home.*

## 5.4. Single Board Hardware Platforms

Many open source single board hardware functions are getting stronger, can compete with PCs. They appear mainly for the purpose of learning and research and have the characteristics of low cost, easy learning, and easy integration. Because different single boards use different SoCs, and the volume of memory are different, the supported communication protocols are different, even these single boards are designed for different purposes. Caused the price, function, stability, and cost of learning are very different. This chapter will focus on the current popular single board and the corresponding models, specifications. In the actual project, make decision with the appropriate single board hardware platform as needed.

### 5.4.1. Raspberry Pi

Raspberry is an ARM-based microcomputer motherboard with SD/MircoSD card as memory. There are a variety of USB interfaces and Ethernet interfaces around the motherboard. At the same time, it has an output interface for video analog signals and an HDMI high-definition video output interface. Have the basic accessories of a PC. With tiny, lightweight, low cost, programmable, easy to integrate and other features. It is very easy to combine with Arduino.

The following table lists the different models of the Raspberry Pi boards and their corresponding specifications.

| Mode | CPU | Memory | USB | Wireless | Bluetooth | Ethernet | HDMI | Release |
|---|---|---|---|---|---|---|---|---|
| 4B | Broadcom Quad core Cortex-A72 (ARM v8) 64-bit 1.5GHz | 1GB 2GB 4GB | 2xUSB 3.0 2xUSB 2.0 | 2.4 GHz and 5.0 GHz IEEE 802.11ac wireless | Bluetooth 5.0/ BLE | Gigabit Ethernet | 2 × micro-HDMI ports (Supports 4K) | 2019 |
| 3 B+ | Broadcom Cortex-A53 (ARMv8) 64-bit SoC @ 1.4GHz | 1GB | 4xUSB 2.0 | 2.4GHz and 5GHz IEEE 802.11.b/g/n/ac wireless LAN | Bluetooth 4.2/BLE | Gigabit Ethernet over USB 2.0 | Full-size HDMI | |
| 3 B | Broadcom Quad Core 64-bit 1.2GHz | 1GB | 4xUSB 2.0 | BCM43438 wireless LAN | BLE | 100 Base Ethernet | Full-size HDMI | |
| 3 A+ | Broadcom Cortex-A53 (ARMv8) 64-bit SoC @ 1.4GHz | 512 MB | 1xUSB 2.0 | 2.4GHz and 5GHz IEEE 802.11.b/g/n/ac wireless LAN | Bluetooth 4.2/BLE | No | Full-size HDMI | |
| 2 B | Broadcom Quad Core ARM Cortex-A7 900MHz | 1GB | 4xUSB 2.0 | No | No | 100 Base Ethernet | Full-size HDMI | |
| 1 B+ | | | 4xUSB 2.0 | No | No | 100 Base Ethernet | No | 2014 |
| 1 A+ | | | 1xUSB 2.0 | No | No | No | | |
| Zero W | Broadcom Core 1 GHz | 512MB | | 802.11 b/g/n wireless LAN | Bluetooth 4.1/ BLE | | Mini HDMI | |
| Zero | Broadcom Core 1 GHz | 512 MB | 2xUSB 2.0 | No | No | No | Mini HDMI | |

*Table 1 Raspberry Pi Board Specification*

The latest generation Raspberry Pi 4 model B board structure below:

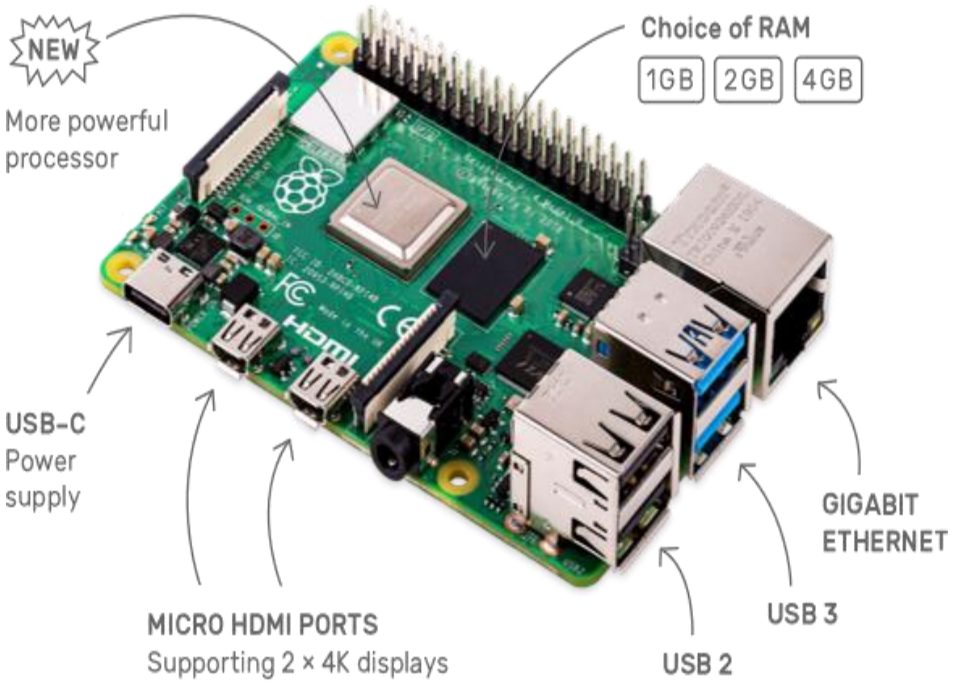


*Figure 13 Raspberry Pi 4 Model B*
*Source: Raspberry.org. (2019).*

### 5.4.2. Arduino

Arduino is a lightweight, flexible, convenient and easy-to-use open source electronic prototyping platform. It includes a hardware development board and a software development environment IDE. The first Arduino was released in 2005. It uses a development language Processing/Wiring similar to Java, C programming style and ARM architecture CPU. It is cross-platform, open source, community active, and easy to learn. And seamless integration with Raspberry.

The following table lists the different models of the Arduino boards and their corresponding specifications.

| Mode | Microprocessor | Flash Memory | Clock Speed | Digital I/O Pins | PWM Digital I/O Pins | Analog Input Pins | SRAM | EEPROM |
|---|---|---|---|---|---|---|---|---|
| UNO R3 | ATmega328P | 32KB | 16MHz | 14 | 6 | 6 | 2KB | 1KB |
| Leonardo | ATmega32u4 | 32KB | 16MHz | 20 | 7 | 12 | 2.5KB | 1KB |
| Mega | Atmega2560 | 256KB | 16MHz | 54 | 0 | 16 | 8KB | 4KB |
| Nano every | ATMega4809 | 48KB | 20MHz | 16 | unknown | 9 | 6KB | 256B |
| Micro | ATmega32U4 | 32KB | 16MHz | 20 | 7 | 12 | 2.5KB | 1KB |
| Yun | ATmega32U4 | 32KB | 16MHz | 20 | 7 | 12 | 2.5KB | 1KB |
| Due | AT91SAM3X8E | 512KB | 84MHz | 54 | 12 | 12 | 96KB | unknown |

*Table 2 Arduino Boards Specification*

The Arduino UNO REV3 board structure below:


*Figure 14 Arduino UNO REV3*
*Source: Store.arduino.cc. (2019). Arduino Uno Rev3.*

### 5.4.3. XBee

Zigbee is a low-power LAN protocol based on the IEEE 802.15.4 standard specification. In 2004, 2006 and 2007, different versions were released. XBee is a series of the single board computer that offers design freedom with easy to integrate functionality and flexible wireless connectivity produced by DIGI, a well-known IoT solution provider in the United States.

The following table lists the different models of the XBee board series and their corresponding specifications.

| Series | Model | Processor | Memory | USB | NIC | Wireless | Bluetooth | Display |
|---|---|---|---|---|---|---|---|---|
| Rabbit BL4S100 series | BL4S110 | Rabbit 4000 40MHz | 1MB | No | 1x RJ-45 Ethernet 10Base-T | Zibgee enabled | No | No |
| | BL4S160 | | 2MB | No | | | No | No |
| Rabbit BL4S200 series | BL4S200 | Rabbit 4000 59.98MHz | 1MB Serial | No | 1 RJ-45 Ethernet 10/100Base-T, 3 LEDs | Zibgee enabled | No | No |
| | BL4S 210 | | 512KB Parallel | No | 1 RJ-45 Ethernet 10 Base-T, 2 LEDs | | No | No |
| Rabbit LP3500 series | LP3500 | Rabbit 3000 7.4MHz | 512KB (2x256K) | No | No | Zibgee enabled | No | LCD 122x32 graphic display |
| | LP3510 | | 256KB | No | No | | No | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Rabbit BL2100 series | BL2110 | Rabbit 2000 22.1 MHz | 256KB | No | 1x RJ-45 Ethernet 10Base-T | Zibgee enabled | No | Option for serial display |
| | BL2120 | | | No | No | Zibgee enabled | No | |
| | BL2130 | | | No | No | Zibgee enabled | No | |
| Rabbit BL2600 series | BL2600 | Rabbit 3000 44MHz | 512KB | No | 1 RJ-45 Ethernet 10/100Base-T, 3 LEDs | Zibgee enabled | No | No |
| | BL2610 | Rabbit 3000 29MHz | | No | No | Zibgee enabled | No | No |

*Table 3 XBee Rabbit Boards Specification*

The Rabbit BL4S100 series BL4S160 model board structure below:

*Figure 15 DIGI XBee Rabbit SBC BL4S100 Series BL4S160 Model*
*Source: Digi.com. (2019). Single-Board Computer | Digi International.*

### 5.4.4. PINE64

PINE64 is an open-source single board hardware community which launched in 2015. The advantages of its boards released that the better hardware, but the price is not expensive. There have high cost-effective on it.

The following table lists the different models of the PINE 64 boards and their corresponding specifications.

| Model | Processor | Memory | USB | NIC | Wireless | Bluetooth | Display |
|---|---|---|---|---|---|---|---|
| A64(+) | Allwinner A64 Quad Core SOC with Mali 400 MP2 GPU | DDR3 RAM (up to 2GB) | 2xUSB 2.0 | Gigabit Ethernet | Optional 802.11gbn | Bluetooth 4.0 expansion module | HD Digital Video Out |
| A64-LTS | Allwinner A64 Quad Core SOC with Mali 400 MP2 GPU | LPDDR3 RAM (up to 2GB) | 2xUSB 2.0 | Gigabit Ethernet | Optional 802.11gbn | Bluetooth 4.0 expansion module | HD Digital Video Out |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| ROCK64 | Rockchip RK3328 Quad-Core SOC with Mali 450MP2 | LPDDR3 RAM (up to 4GB) | 2xUSB 2.0 1xUSB 3.0 | Gigabit Ethernet | Unknown | Unknown | 4K Digital Video Out |
| ROCKPro64 | Rockchip RK3399 SOC with Mali T860 MP4 GPU | LPDDR4 RAM (up to 4GB) | 2xUSB 2.0 1xUSB 3.0 1xUSB-C | Gigabit Ethernet | Optional 802.11 AC | Bluetooth 4.0 / 5.0 expansion module | DSI Port |
| H64 Model B | Allwinner H6 Quad-Core SOC with Mali T-722 MP2 | LPDDR3 RAM (up to 3GB) | 2xUSB 2.0 1xUSB 3.0 | Gigabit Ethernet | Integrated Wi-Fi 802.11n | Integrated Bluetooth 4.0 | 4K Digital Video Out |

*Table 4 PINE64 Boards Specification*

The H64 Model B board structure below:

*Figure 16 PINE64 H64 Model B Board*
*Source: PINE64. (2019). PINE H64 ver. B | PINE64.*

### 5.4.5. Intel

Intel is a technology-leading global company that develops, produces CPU chips and has an absolute lead edge. The company's CPUs account for most of the market in the PCs and servers' areas. At the same time, it is constantly exploring the computing chips and single board hardware in the IoT industry. It also has quite mature solutions in the IoT field such as Home Automation, Smart City, Industrial Automation.

The following table lists the different models of the Intel Single boards and their corresponding specifications.

| Model | Processor | Memory | USB | PCI | Ethernet | Bluetooth | Wireless |
|---|---|---|---|---|---|---|---|
| Galileo | Intel Quark SoC X1000 400MHz 16K cache | DDR3 800 (up to 256MB) | 3xUSB 2.0 | 1xPCI Express 2.0 1xPCIe Gen 2.x 1xPCIe Mini Card Slot | Integrated LAN | No | No |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Galileo Gen 2 | Intel Quark SoC X1000 400MHz 16K cache | DDR3 800 (up to 256MB) | 3xUSB 2.0 | 1xPCI Express 2.0 1xPCIe Gen 2.x 1xPCIe Mini Card Slot | Integrated LAN | No | No |
| Edison | Intel Atom 500 MHz dual-core CPU and Intel Quark 100 MHz microcontroller | DDR3, NAND FLASH (up to 4GB) | 1xUSB 2.0 | No | No | Yes | 802.11n |
| Curie | Intel Quark SE SoC | 384 KB on-die flash, 80 KB on-die SRAM | 1xUSB 2.0 | No | No | Yes | No |
| Joule | Intel Atom 1.5GHz CPU | LPDDR4 (up to 3GB) | 2xUSB 2.0 2xUSB 3.0 | 1xPCIe with USB3 1xPCIe Gen 2.x | No | Yes | 802.11ac |

*Table 5 Intel Boards Specification*

The Intel Joule development board structure below:

*Figure 17 Intel Joule Development Board*
*Source: Software.intel.com. (2019). Development Kit Overview*

## 5.5. Programming Languages

### 5.5.1. C/C++

The C language is a compiled language developed by Bell Labs in 1978, and the original version of the C language is implemented by D.M.Ritchie. In order to realize the cross-platform problem of C language, the ANSI C standard was released in 1983.

C language is a process-oriented programming language. C++ is developed from the foundation of C language. It adopts object-oriented programming mode and uses real-world problems to model and calculate the functions of abstraction, encapsulation, polymorphism and interface. . The biggest feature of the C/C++ programming language is that it proposes the concept of a pointer. Through the operation of the pointer, the programmer can freely allocate the memory to be used and reclaim the released memory. However, if the memory is not released in time, the program may run the risk of memory overflow.

Due to its high execution efficiency, C/C++ is widely used in driver development for embedded devices (small memory, low CPU frequency, no or little external storage).

### 5.5.2. Java

Java is an object-oriented programming language that not only absorbs some of the advantages of C++, but also removes the concepts of multiple inheritance, pointers, and so on. In Java, you don't need to manually release the memory used by variables, but instead it has a garbage collection mechanism. The Java programming language is powerful and cross-platform and is widely used in internet-based web applications and distributed systems. The system layer of the smartphone operating system Android is implemented in Java. The Java source code needs to be compiled to generate bytecode. This bytecode can be interpreted and executed on any host that has a JVM installed to achieve cross-platform capabilities.

The Java programming language was released by Sun in 1996. The current Java platform consists of three parts:

1. J2ME: It used to develop applications for embedded or mobile devices.
2. J2SE: It used to provide basis data structures, algorithms and general-purpose APIs.
3. J2EE: It used to develop an Enterprise scale distributed application based on C/S architecture.

### 5.5.3. Processing/Wiring

Processing is a programming language developed by the Java programming language, primarily for artists, designers, and academic research. It allows developers to focus directly on graphics processing and interaction without having to consider other things that are not related to it. Processing has a very active open source community and users and can easily get support when problems arise. A single board platform IDE of Arduino which uses Processing as a programming language to help programmers quickly achieve their goals according to their needs. But Arduino itself uses a programming language that is Wiring.

### 5.5.4. Python

Python is a high-level programming language for interpreted, object-oriented, and dynamic data types. It was invented by Guido van Rossum at the end of 1989 and the first public release was published in 1991. The Python source code also follows the GPL (GNU General Public License) protocol. Currently, Python is widely used in big data analysis processing, automation scripts and web application development.

For example, there are two very popular web application frameworks in Python: Flask and Django. Flask is a lightweight representation, but Django is the most representative of the heavyweight

framework. There are many python-based web applications developed on the basis of these two frameworks.

Due to its flexibility, there are also a large number of examples in IoT as automation scripts using python. For example, Raspberry Pi provides a lot of python library APIs, programmers can easily call these APIs to enable these devices work stably and communicate with each other.

### 5.5.5. Node.js

Node.js It is based on the JavaScript runtime environment of the Chrome V8 engine. It uses an event-driven, non-blocking I/O programming model. Node.js allows JavaScript to run on the server side in a lightweight and efficient technology, ideal for applications that require distributed computing and client-intensive applications. In recent years, with the development of IoT technology, Single board platform and IoT cloud service support Node.js will also become a trend.

### 5.5.6. Kotlin

Kotlin is Google's official Android development language, developed by JetBrains, to replace the current Java language and the Android SDK. Kotlin source files can be compiled into Java bytecode for easy running on the JVM. At the same time, Kotlin can also be compiled into JavaScript, which runs on devices without a JVM.

## 5.6. IoT Cloud Services

As cloud services continue to evolve, more and more cloud service providers are integrating IoT into the cloud as a service and providing guidance on complete solutions and best practices based on different industries. For example, based on Home automation, logistics automation, smart city, and other solutions.

### 5.6.1. AWS IoT Core

AWS IoT provides a complete set of Home Automation solutions. The solution is a fairly complete IoT ecosystem chain, from the client side, to device management controls, to the home LAN environment, to an intensive management console. In the cloud, the provision of IoT basic services, as well as the integration of other AWS Cloud Services such as big data analytics, artificial intelligence, data storage, etc. ultimately gives data visualization and mobile applications.

**Programming languages support**

Nodejs, .NET, Java, Go, Python, android, iOS, C

**AWS IoT Cloud Home Automation Architecture**

As described below, in the AWS IoT home automation architecture. based on Amazon FreeRTOS, the integration, and expansion of IoT appliances for the user's home. intensive management and monitoring in AWS Greengrass. integration with AWS's IoT cloud services where the resulting data of

IoT appliances are stored and analysed. Combining machine learning can maximize the user's family to have a more reasonable, more efficient, smarter life.

Finally, the data is visualized for display on a smart terminal such as a mobile phone or tablet. The entire process forms an end-to-end closed cycle.


*Figure 18 AWS IoT Cloud Home Automation Architecture*
*Source: Building Home Security Solutions at Scale, F. (2019). IoT for Connected Homes | Home Automation, Home Security & Monitoring, Home Networking | AWS IoT.*

**AWS IoT Home Automation Solution with Alexa**

A solution for integrating Alexa is given in the AWS IoT architecture design. The solution combines Amazon's smart terminal Alexa to integrate Home IoT appliances and interact with the cloud's API Gateway to invoke other cloud services. The architecture mentions streaming data services called Kinesis. Kinesis can provide concurrent data transfer services for thousands of IoT appliances.

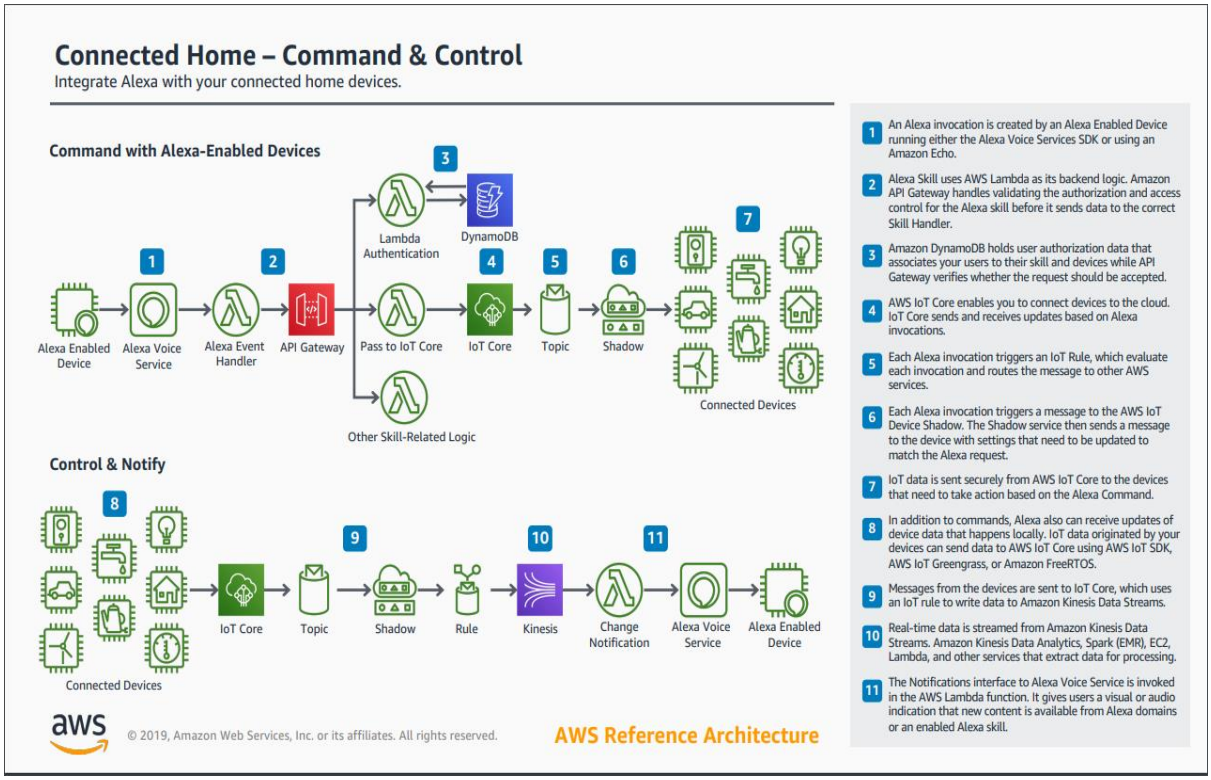


*Figure 19 AWS IoT Cloud Home Automation Solution*
*Source: D1.awsstatic.com. (2019).*

### 5.6.2. Google Xively

Xively is an IoT platform that was acquired by Google in 2018. According to Google's plan, it will integrate it with Android, Google cloud platform, and Google IoT to form a complete solution.

**Programming languages support**

Nodejs, .NET, Java, Go, Python, android, iOS, C

**Google Xively Platform Architecture**

The Xively platform provides the ability to integrate IoT appliances and provide intensive management of appliances for mobile apps and Web UI, as well as reliable communication networks , security mechanisms, and user authentication management, etc. Easy to integrate with other external third-party systems. Provide solutions for industrial automation and home automation.

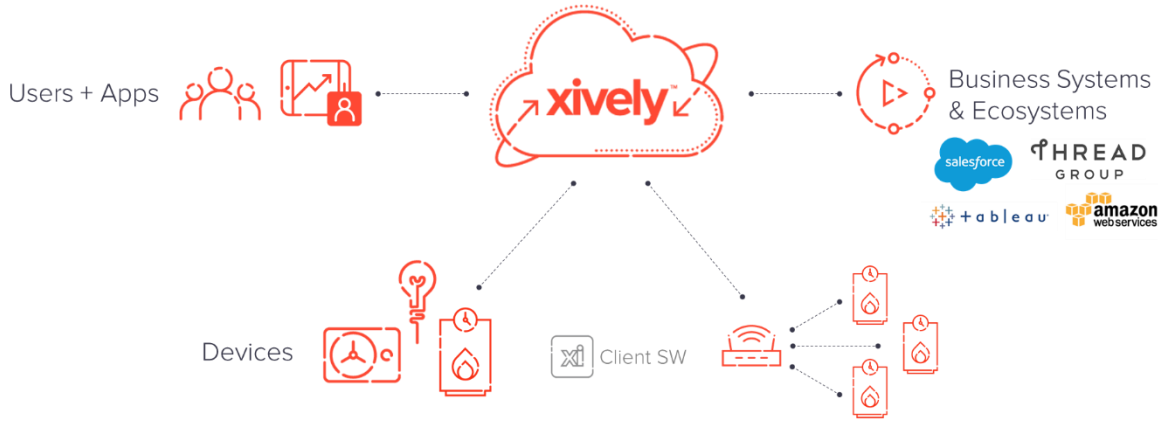


*Figure 20 Google Xively Architecture*
*Source: Developerxively.com. (2019). What is Xively?*

**Xively Connected Product Management Platform Architecture**

Connected Product Management (CPM) Platform in Xively provides the ability to connect securely devices and users that base on basic infrastructure. It also has a set of operation tool that offers features which firmware deployment, permissions, logs, monitoring and alerting. On the aspect of management ability, it is able to integrate 3rd part systems such as CRM or services such as AWS cloud services. It manages the rule and orchestrations that react to product and user activity. Finally, it has given the data visualization on top of Xively data.

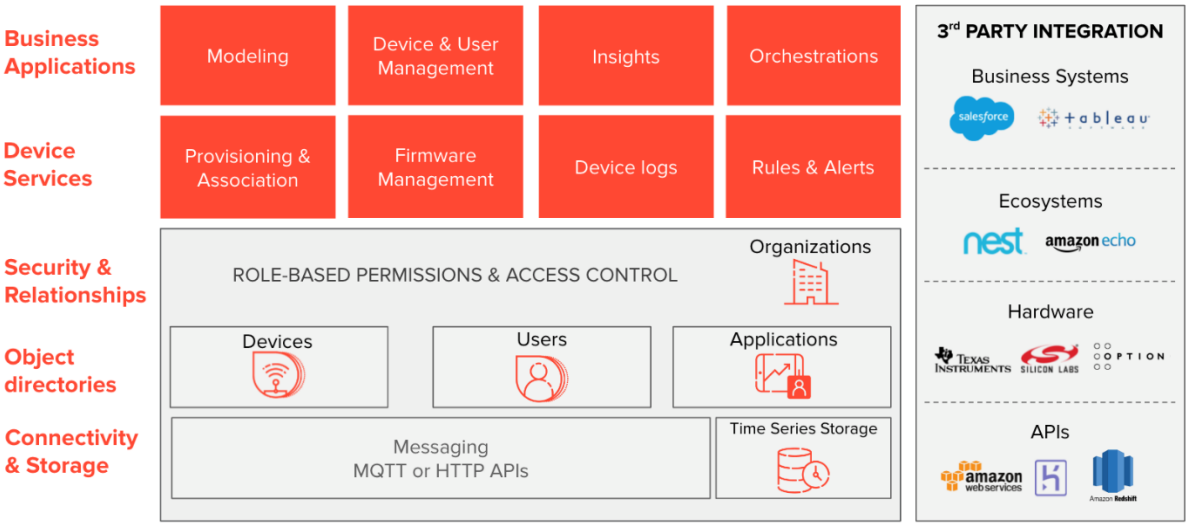


*Figure 21 Google Xively CPM Architecture*
*Source: Developerxively.com. (2019). What does Xively give me?*

### 5.6.3. Microsoft Azure IoT

The Azure IoT is a set of services that is able to connect, monitor, and manage billions of IoT appliances, and managed by Microsoft Azure Cloud. It gave a series of solution that relies on itself strong cloud services ability to meet the needs of industries that include government, finance, retail, manufacturing, energy, home automation, and etc.

**Programming languages support**

Nodejs, .NET, java, python, android, iOS, C

**Azure IoT Technologies and Solutions**

The Microsoft Azure IoT technologies and solutions were built on the top of the PaaS and SaaS.

On solution, the PaaS can help you to quickly build the application using IoT solution accelerators and Digital Twins both services, the SaaS provide you the IoT Central to fast develop IoT applications reduce the complexity of IoT solution.

On technologies, the PaaS offers the basic infrastructure of the IoT to ingrate and manage the millions of IoT devices to bi-directional communications with IoT Hub. Finally, the PaaS data analytics offers big data processing then give user data visualization.

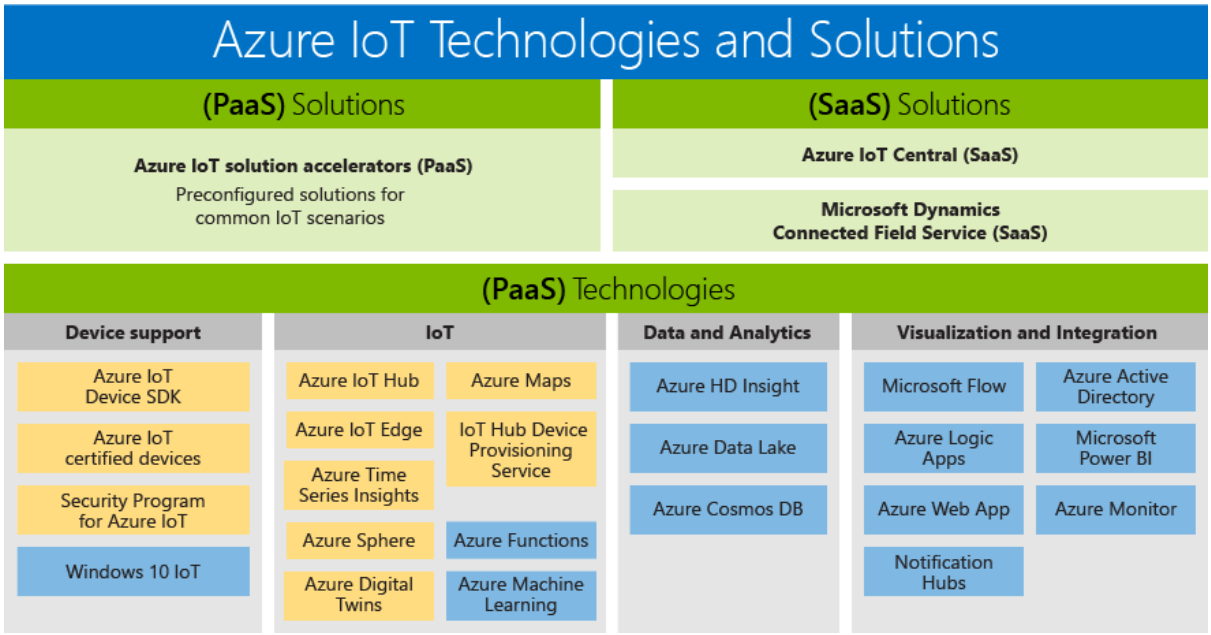


*Figure 22 Microsoft Azure IoT Technologies and Solutions*
*Source: Docs.microsoft.com. (2019). Azure Internet of Things (IoT) technologies and solutions.*

**A series features of Azure IoT services**

In this part, it would introduce a series of the IoT services. The features of Azure IoT services detailed below.

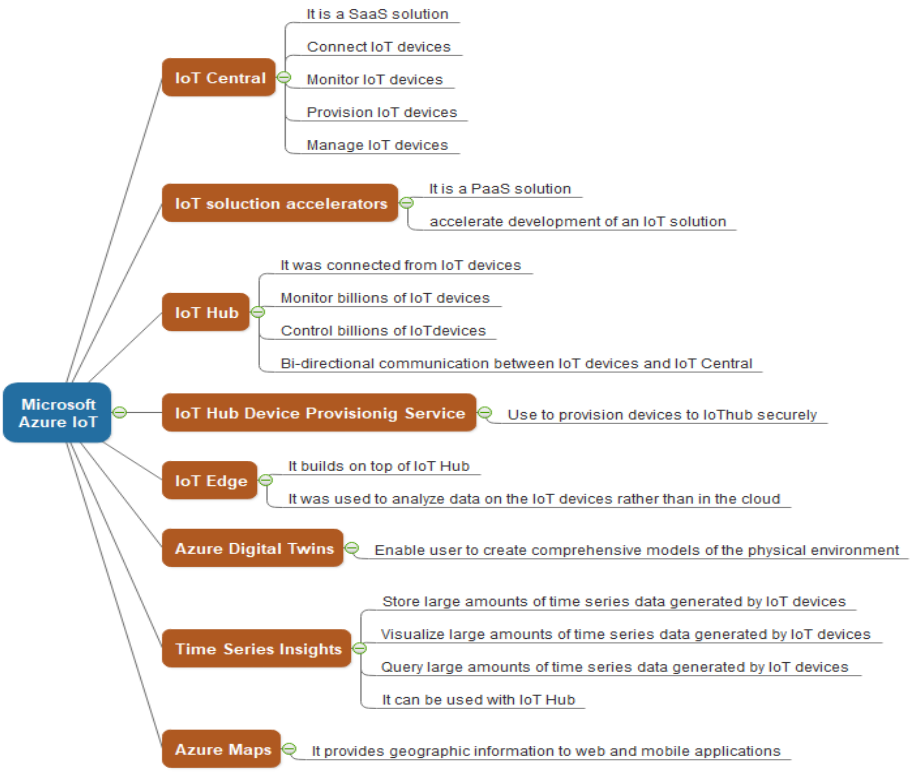


*Figure 23 The Features of the Azure IoT Services*

### 5.6.4. Aliyun IoT Platform

Alibaba Cloud IoT platform provides secure and reliable connection and communication capabilities for devices. It connects massive devices and supports device data collection on the cloud. The cloud API is provided upwards, and command data is sent to the device through API calls for remote control. The device connects to the Internet of Things platform and communicates with the Internet of Things platform. The IoT platform can stream data of devices to other Alibaba Cloud services for storage and processing.

The IoT platform also provides other value-added capabilities such as device management, rules engine, data analysis, edge computing, etc., to empower various IoT scenarios and industry developers.

**Programming languages support**

Java, Python, PHP, .NET

**Aliyun IoT Platform Architecture**

Aliyun IoT Platform provides the client-side SDK that is able to fast implement communicates between cloud service and devices, which is more efficient. Meanwhile, the architecture supports horizontal expansion and easy to integrate the other cloud services of Aliyun.

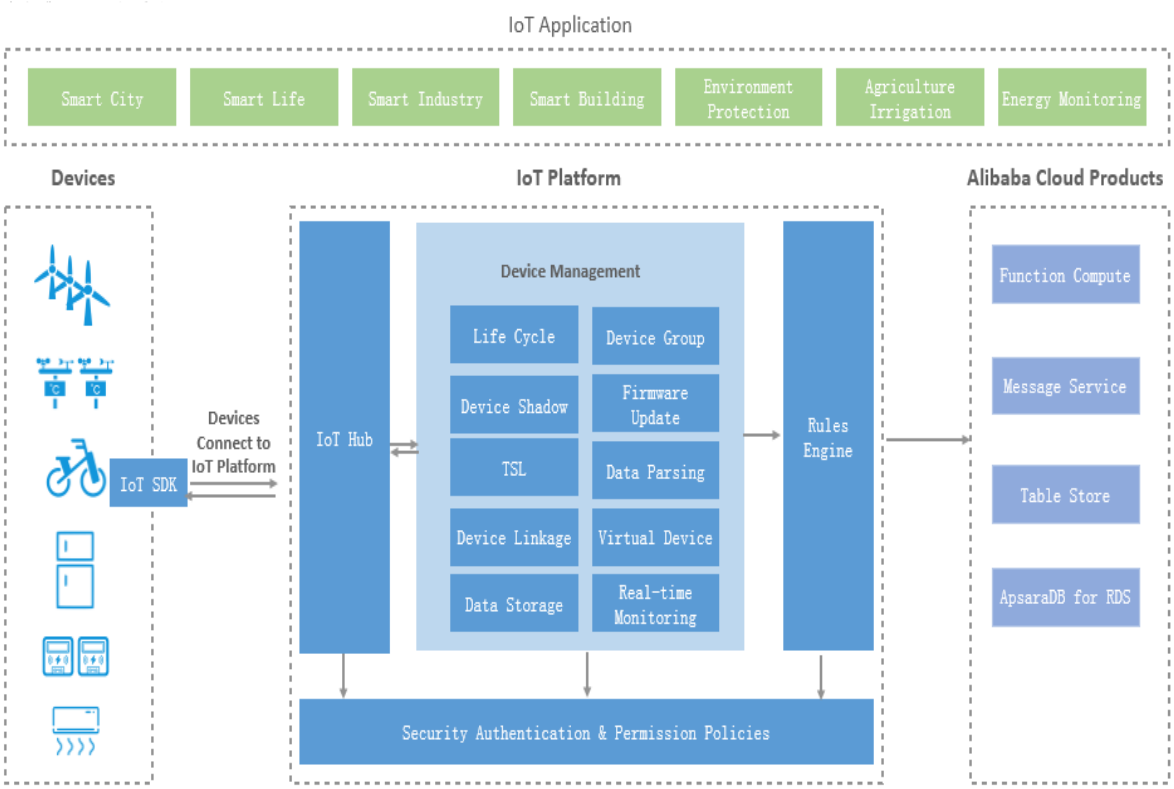


*Figure 24 Aliyun IoT Platform Architecture*
*Source: Alibabacloud.com. (2019). Architecture - Product Introduction| Alibaba Cloud Documentation Centre.*

## 5.7. Data Storage Technologies

In the Internet of Things, The IoT appliances generate a lot of small pieces of data, which will take up a lot of storage space through continuous accumulation. Due to the limitations of the IoT appliances, storage space is very limited. So developers or designers have to consider better solutions to the problem of data storage. This chapter will discuss four common data storage solutions.

### 5.7.1. DAS

DAS is called Direct Attach Storage. This storage method connects storage devices to the host. For example, the PC we use is a DAS connection to the storage device - the hard disk. It has low management costs and is simple to implement. Because of the direct attachment to the host, data sharing loves certain limits. We can also call it local storage.

### 5.7.2. NAS

NAS is called Networking Attached Storage. It can read and write files between multiple file servers over the network. Commonly used NAS network protocols are NFS, SMB, and CIFS to implement file sharing across networks. This approach centrally manages business system data stored on different servers and provides cross-network access capabilities. However, this method is reliable and suitable for small LAN operations.

### 5.7.3. SAN

The SAN is called Storage Area Networks. It uses high-speed fibre-optic networks to connect servers and storage devices. Storage sharing is achieved based on various advanced protocols such as SCSI, IP, and ATM. The advantage of this approach is that the server and the storage device are independent of each other and perform their duties. And the use of optical fibre for communication, high-performance, high-stability storage environment. But the shortcomings are also very obvious, its implementation is quite complicated, and the management cost is too high.

### 5.7.4. Cloud Storage Services

Cloud storage service that is a kind of file object read and write APIs provided by cloud service providers. The service can be called by the client to store the file objects that need to be stored to the cloud-hosted storage device. When needed, the client can also read the specified file object from the cloud-hosted storage device through the service API. Cloud storage services are often provided, whether public or private. For example, AWS, Google, and MacroSoft's cloud platforms are all known to provide paid cloud storage services.

The advantage of cloud storage is that it stores data in the cloud, and it is easy to integrate with other cloud services of the cloud platform, and analyse and process the data, which can largely compensate for the lack of computing power of the IoT device. The disadvantage is that the cost is relatively high, completely dependent on the internet, and there is a certain network delay.

## 5.8. Smart Phone and Tablets

In the Internet of Things, the use of Smart phone or tablets as an intensive control centre is becoming more common. Especially in the home automation applications. This section will introduce some common mobile device operating systems and app development frameworks.

### 5.8.1. Mobile Operating Systems

According to the data from Statista website indicates that mobile operation system market share in July 2019, there is more than 98% market occupied by Android and iOS. Android is the most popular, accounting for 76.08% of the market share.

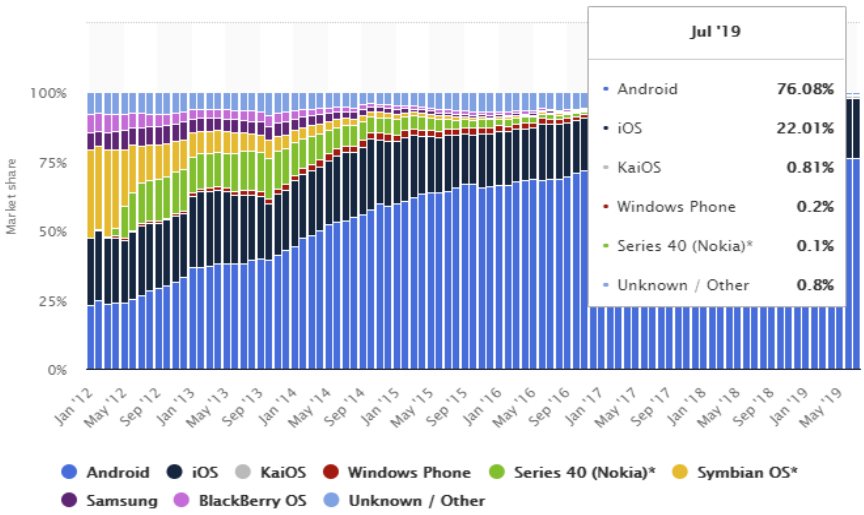


*Figure 25 Mobile Operating Systems' Market Share Worldwide*
*Source: Statista. (2019). Mobile OS market share 2019 | Statista*

### 5.8.1.1. Android

The Android operating system was originally developed by Andy Rubin and used as the operating system for smartphones. It was acquired by Google in August 2005. It is an operating system based on the Linux kernel and open source. Currently, Android is used in a variety of mobile devices, such as smartphones, tablets, laptops, game consoles, smart watches, and televisions. Currently, Android occupies the vast majority of the smartphone operating system market. The operating system is implemented in C/C++, and the application layer is implemented in Java. Currently, the latest version is Android 11.

The Android mobile operating system architecture below:

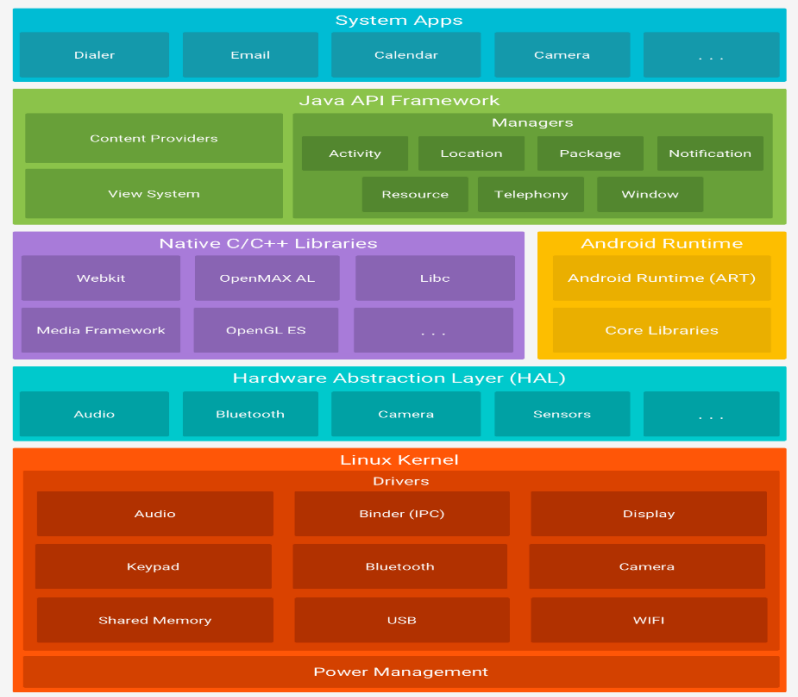


*Figure 26 Android Mobile Operating System Architecture*
*Source: Android Developers. (2019). Platform Architecture | Android Developers.*

#### 5.8.1.2. iOS

iOS is a mobile operating system for mobile devices developed by Apple. It supported iPhone, iPod touch and iPad, etc. iOS does not support any non-Apple designed hardware devices. It runs more smoothly, stable than Android. Currently, the latest version is iOS 13. It is the same as Mac OS, both built on top of the Unix.

The Android mobile operating system architecture below:

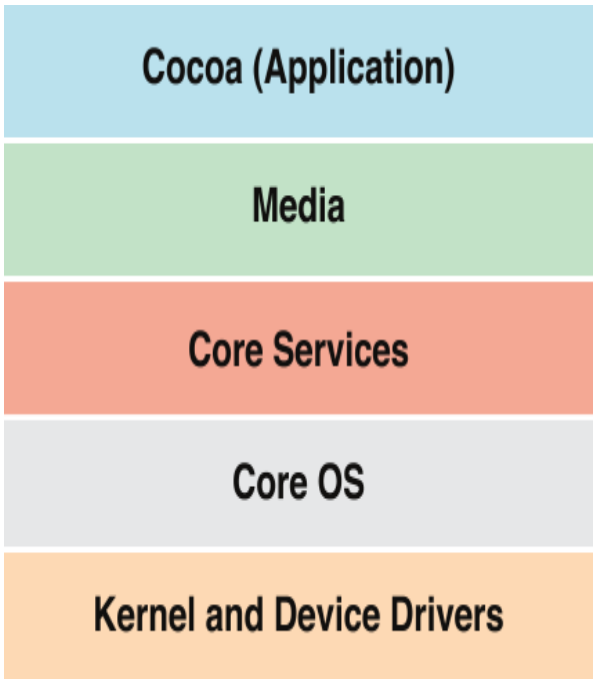


*Figure 27 iOS Mobile System Architecture*
*Source: Developer.apple.com. (2019). About Developing for Mac*

#### 5.8.1.3. Windows 10 Mobile

Windows 10 Mobile is an operating system for mobile devices, developed by Microsoft. It also supports UWP (Universal Windows Platform) applications that run across platforms. On December 22, 2018, Microsoft announced on its official website that it will stop releasing security and software updates for the Windows 10 Mobile operating system on December 10, 2019 and will stop technical support for related devices.

The reason for the failure of Microsoft's mobile operating system is that it has not enough support from other vendors in terms of software and hardware and failed to provide enough apps in the app store for users.

### 5.8.2. Mobile App Development Frameworks

According to the differences in the process of mobile app development, update, deployment, etc., and the way it runs on the mobile operating system, we have divided the development framework of the mobile app into three categories: Native app, Web-based app and Hybrid app.

#### *5.8.2.1. Native App*

Native As a traditional development model, it is necessary to develop languages and frameworks for different smart device operating systems such as iOS, Android, and Windows Mobile. This development method drives the underlying hardware device by directly calling the device's API, so the published app has the highest performance, the user experience is good, and the application runs smoothly. But correspondingly, it is necessary to develop and maintain different release versions for different mobile phone platforms, and the cost is very high. If the update is released, the user needs to reinstall the app.

The current major smart phone app development kits include:

1. Android SDK
   Android SDK refers to the exclusive software development kit released by Android written by Java programming language. It is a collection of development tools used by software development engineers to build an app for the Android platform. It offers a collection of the APIs to interact with the underly hardware layer of the mobile phone. The SDK has already integrated into the Android Studio where is an Android app development tool.

2. iOS SDK

   iOS SDK refers to the exclusive software development kit released by Apple that supports Swift and Object-C both programming languages. The SDK allows the developer to implement the mobile apps and finally can runs on the iOS operating system. It also provides a collection of the APIs to interact with the underly hardware layer of the Apple devices. Combined with the XCode which is an iOS app development tool to quickly develop an app then release the app on the iOS app store.

#### *5.8.2.2. Web-based App*

The app deployment package generated by the Web-based mobile app development framework is actually a web application, which is parsed and executed by the web kit engine integrated under the mobile hardware platform. The underlying device API cannot be called directly because it runs entirely on top of the web parsing engine. When the page state changes, the web kit engine re-renders the entire page instead of directly notifying the underlying hardware to render.

Therefore, the performance is very low, the system is not running smoothly, and the user experience is not good. The advantage is that this method can be cross-platform, and the deployed deployment package can adapt to all smart device operating systems. When there is an update or upgrade, the mobile terminal does not need any update, which greatly reduces the operation and maintenance cost.

Because this way the user experience is very bad, it will gradually be eliminated in future of the industry.

#### *5.8.2.3. Hybrid App*

The Hybrid App is an app development solution between the native app and the web-based app. The program combines the advantages of both native and web-based apps. When you need to interact with the underlying hardware (such as calling a camera), use the device's native APIs. When the user layouts and interacts with the UI layer, it uses the JavaScript, CSS and HTML5 technologies that the

web can parse. Between native APIs and web technologies, a technique called Bridge is used to communicate with each other.

This way to develop a mobile app, both cross-platform and user experience. Greatly reduce maintenance costs and make the app release more efficient. Here are three mobile app development frameworks that are very popular in the hybrid field. For web front-end developers, these frameworks can be used to develop cross-platform, easy-to-maintain mobile app with minimal learning costs.

1. React Native

   React Native is an open-source cross-platform mobile app development framework released by Facebook in April 2015. It currently supports iOS and Android devices. React Native uses JSX that can combine the implementations of the HTML, CSS and JavaScript together, then JSX was compiled and execute to interact to native components of the mobile device.

2. Flutter

   Flutter is a mobile app development framework written in Dart programming language released by Google. Announcing the first preview verion v1.0 in December 2018. Subsequently, it became more and more popular in the field of mobile app development. It targets different mobile platform to abstract a different UI style such as material UI in Android and Cupertino UI in iOS. It is able to fast develop a cross-platform mobile app using flexible UI design and give you native performance experience.

3. Xamarin.Forms

   Xamarin.Forms is a cross-platform mobile app development framework that allows developer to implement easily an app which can run on Android, iOS and UWP (Universal Windows Platform) from a single shared codebase. It also an open-source framework written in C# released by Microsoft.

## 5.9. Open-source Home Automation Systems

With the rise of the IoT industry and the continuous maturity of solutions. More and more home automation open-source platforms have emerged. In this chapter, there will be a focus on three excellent home automation open-source platform.

### 5.9.1. OpenHAB

The openHAB is an abbreviation for Open Home Automation Bus which is an open-source platform that acts as a core of the smart home. The platform was created by Kai Kreuzer in 2010. Currently, openHAB has integrated mounts of devices and technologies.

OpenHAB also offered the Web UIs, Native App with Android and iOS to configure and control the devices of the smart home. It has already integrated rules engine and logging system internally and allows users to dynamically configure rules and UI layouts based on the plain text formatting. It is able to run well on the x86 or ARM CPU architecture with 512MB.

The architecture overview of the OpenHAB platform below.

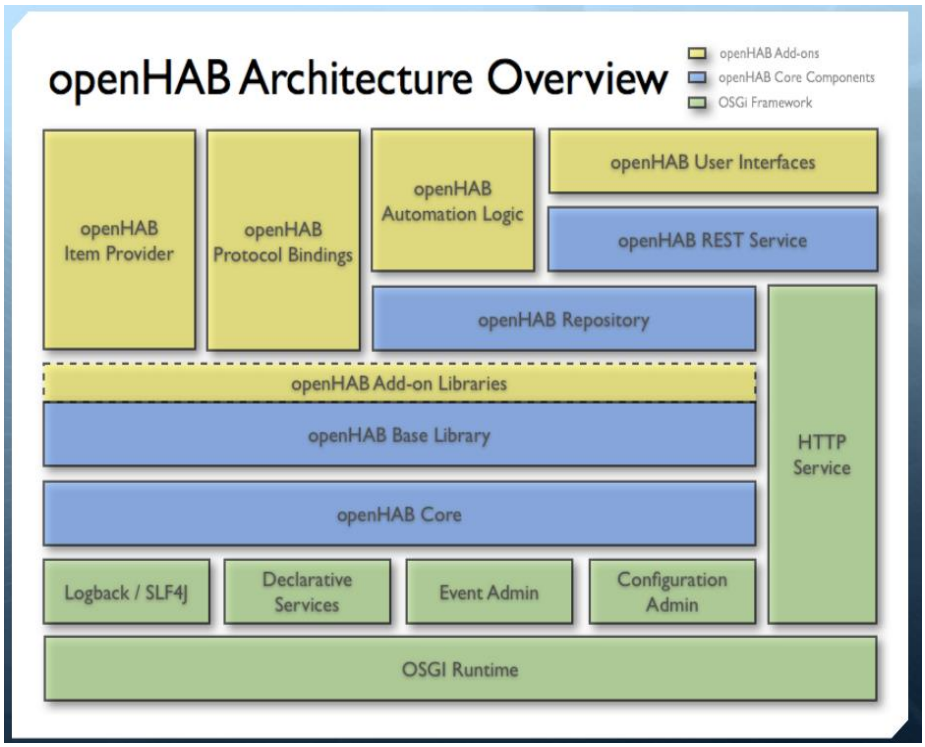


*Figure 28 OpenHAB Architecture Overview*
*Source: Porter, M. (2017). Building IoT systems with openHAB*

The advantages of OpenHAB include:

- ✓ It is open-source platform written in Java.
- ✓ Excellent device coverage.
- ✓ Independent of hardware and Independent of manufacturer.
- ✓ Regular updating and robust community support.
- ✓ Superior scalability.
- ✓ Security assurance and works offline.
- ✓ RESTful APIs for prompt system integration

### 5.9.2. Home Assistant

Home Assistant is an open-source home automation platform puts local control and privacy first. It has very active community and many third-party add-ons that have been developed are placed in the hass.io repository, that add-ons are able to easily integrate into you home automation system. It also provides graphical user interface for device configuration, management, monitoring and data visualization in desktop application and mobile app to customizable and powerful way for users to manage their home. The home assistant has powerful privacy protected mechanism to avoid the risk of data leakage.

The overview of the Home Assistant core architecture below.

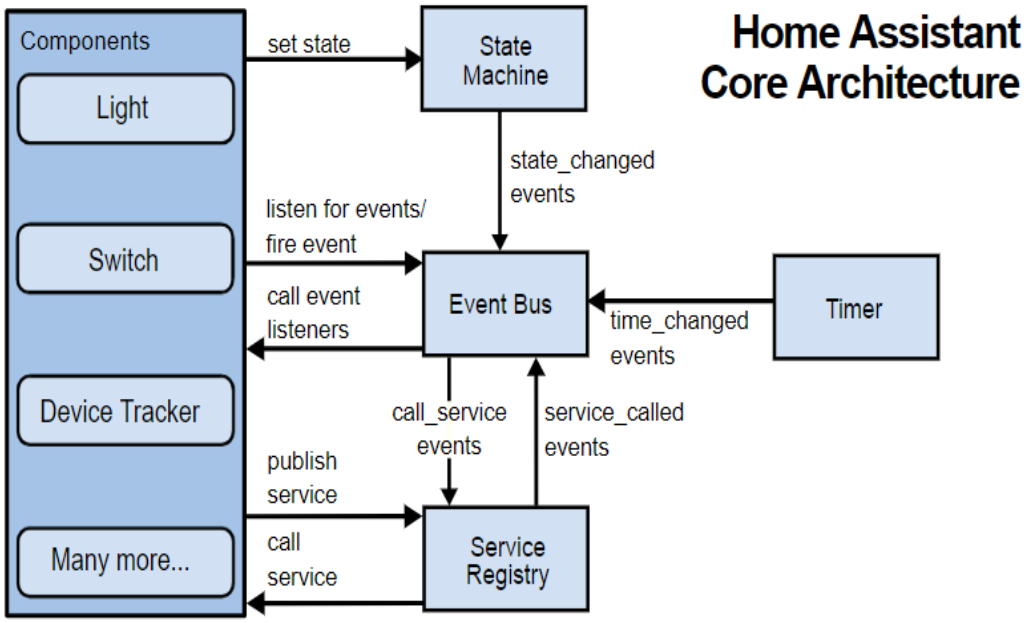


*Figure 29 Home Assistant Core Architecture*
*Source: Developers.home-assistant.io. (2019). Architecture · Home Assistant dev docs.*

The advantages of Home Assistant are mentioned in official website:

- ✓ It is open source and free.
- ✓ Optimized for embedded devices like Raspberry Pi.
- ✓ 100% local home automation.
- ✓ Easy installation and updates powered by HassOS and Docker.
- ✓ Management web interface integrated into Home Assistant.
- ✓ Create and restore full backups of you whole configuration with ease.
- ✓ Install many popular add-ons with a single click, such as
  - Google Assistant
  - Encryption via Let's Encrypt
  - Dynamic DNS via Duck DNS
  - etc.
- ✓ Active community

### 5.9.3. Node-RED

The Node-RED is an open-source project that was launched in 2013 by IBM in the IoT field takes advantage of Node.js to implement. It is a simple and powerful automation platform. There is a visualization tool to build flowcharts with simple scripting and programming to produce an automation experience. That is an easy way to troubleshooting with the visualization flowcharts. It extends simply to add new capabilities and types of integration.

But it is not a fully scalable, high-performance, enterprise-capable application runtime. This platform is a lightweight proof of concept runtime.

The overview of Node-RED architecture below.

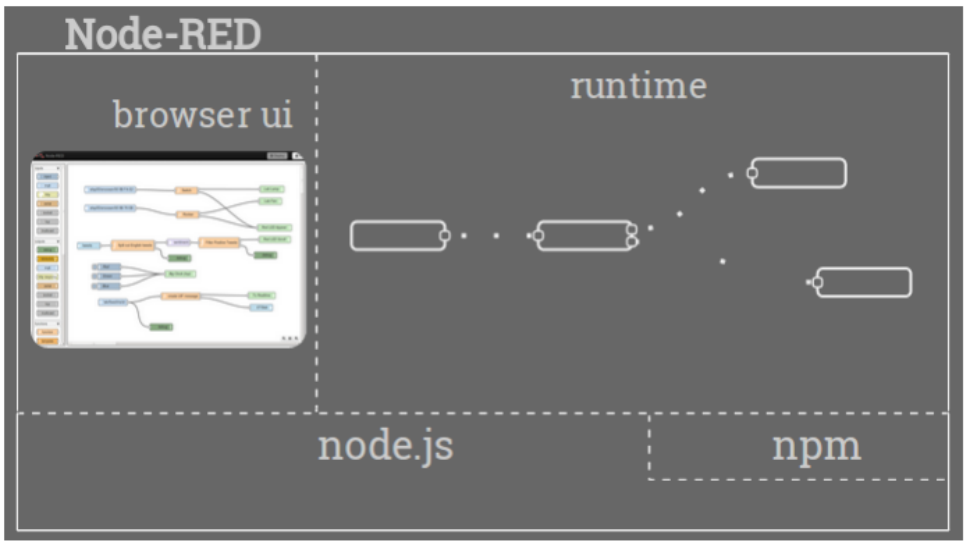


*Figure 30 Node-RED Architecture*
*Source: Ibm.com. (2019) Bluemix*

The advantages of Node-RED include:

- ✓ Built on Node.js that more flexible.
- ✓ Event-driven and non-blocking model.
- ✓ Low-code programming for applications.
- ✓ Browser-based flow editing.
- ✓ Built-in library re-use.
- ✓ Troubleshooting visualization
- ✓ Collaboration Development through imported and exported flow files.

## 5.10. Home Automation Manufacturers

### 5.10.1. SmartThings

SmartThings is an American technology company in IoT Field that set up with a home hub, cloud platform, and home appliances in the automation home environment. It was founded in 2012 and was acquired by Samsung in August 2014.

*Figure 31 SmartThings Brand Logo*
*Source: SmartThings.com. (2019). SmartThings.*

The primary products of the SmartThings contain a mobile app, a home hub, and a variety of sensors and appliances. The mobile app allows users to control, monitor, and automate their home environment via a terminal device such as smartphones or tablets. The home hub as an intensive management console that can connect to the internet, as well as compatible multiple local network communication protocols such as Zigbee, Z-Wave, etc.

So far, SmartThings supports 12 different categories of devices that belong to 27 well-known brands of home appliances manufacturers, a total of 204 household appliances. such as Amazon Echo, Google Home, IKEA LED bulbs, Bose speakers, Samsung washing machine, Samsung robot vacuum, and so on.

### 5.10.2. Control4

Control4 also is an American technology company that is a leading provider of home automation industry. It was founded in 2003 as an early entrant in the home automation customer market that offers products such as home network, home security, climate control, smart lighting, intercom, multi-room audio, and so on.


*Figure 32 Control4 Brand Logo*
*Source: Control4.com. (2019). Catalog.*

Control4 has its own smart home operating system, as well as an e-magazine called Smart Home for consumers to subscribe for free. Their home automation solutions and industrial cases cover smart businesses such as restaurant & bar, boardroom, hotel, fitness & SPA, as well as clinical office, etc.

The products below, that categories contain home network, security, climate control, lighting, intercom, audio, home theatre, as well as remote and voice control, and so on.


*Figure 33 Control4 Product List*
*Source: Control4.com. (2019). Catalog.*

Smart Home E-Magazine that offers the trends in home automation Field.


*Figure 34 Control4 Magazine*
*Source: Control4.com. (2019). Smart Home Magazine 2018.*

### 5.10.3. Xiaomi

Xiaomi is a Chinese technology company that involved the smartphone, smart devices, and IoT fields. It was founded in 2010. Xiaomi offers an IoT platform that orient enterprise developers, which is not yet open to individual developers. It can help the enterprise developers quickly to integrate their device into Xiaomi products of Home automation. The IoT platform is currently only available to companies in mainland China.

*Figure 35 Xiaomi Brand Logo*
*Source: Mi.com. (2019). Xiaomi Global | Official Website | Mi.com - Mi Global Home.*

So far, the xiaomi Home automation has already developed the products that integrated the smart devices and services. The products below, that categories involve sockets & sensors, lighting, home network, climate control, health care, home appliances, cleaning assistant and so on.

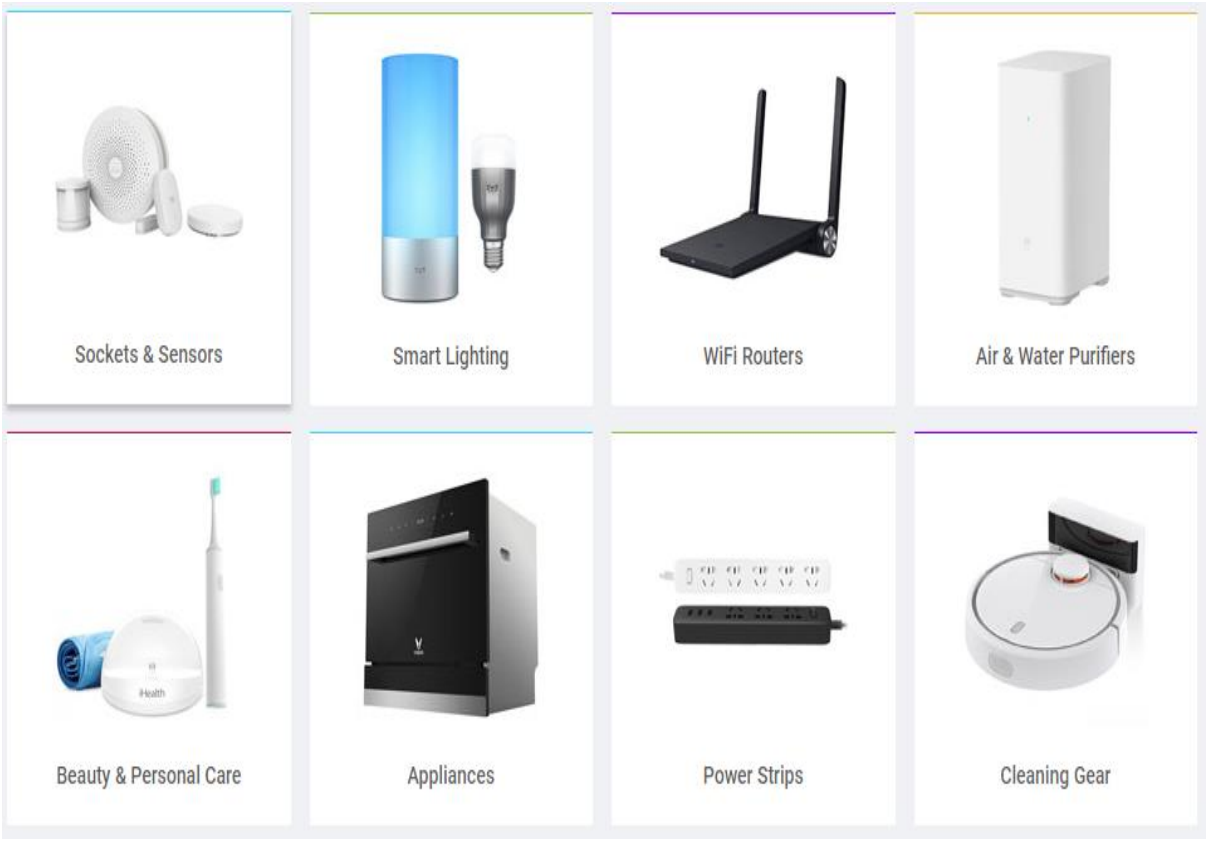


*Figure 36 Xiaomi Home Automation Product List*
*Source: Community, X. and Devices, S. (2019). Xiaomi Mi Smart Home - category of Xiaomi smart devices and accessories for it | XIAOMI-MI.com.*

# 6. Home Automation Applications

## 6.1. Energy Management

Reducing energy consumption has become a very urgent desire to have new technological breakthroughs in modern society, which has a major impact on the future development. While the technology development process requires more and more energy, but the energy resources are more and more limited. So here are two main areas of application for performance:

- Energy saving that is designed to use the sensors and actuators in smart homes to control energy saving, to determine whether it is not currently used or according to user preference settings. Shutdown or low power mode.

- Smart grid integration integrates the energy awareness of home automation into smart grids.

## 6.2. Comfort and Lighting

Home automation should provide a comfortable way for users to easily and intensively switch lights through the remote control or voice control from a smart device, as well as monitoring the lights work and energy consumption.

## 6.3. Home Entertainment

A typical and special feature of home automation is to solve users' leisure and entertainment. Usually more efficient is to integrate third-party mature and stable services. For example, build a home cinema, it can integrate Netflix. A game centre that can integrate Microsoft Xbox. A TV system that can integrate service from a cable TV provider. An internet video website that can integrate service from Google YouTube. etc.

## 6.4. Control and Connectivity

The control system may be the most complicated part of home automation. Its applications include providing users' behavioural responses to specific events. In this case that involves interactions between persons, interactions between human and devices, as well as interactions between devices. So in the home automation field, abstract three important concepts:

- In the real world, a physical thing may be represented in the abstract information world via one or more virtual things.
- The hardware infrastructure of the object must have intellectual capabilities. For example, the devices are capable of being sensed and produce the data.
- The software layer provides the intelligent function of the object. For example, the software should trigger behavioural events when a command is received or the environment changes.

## 6.5. Security

Home automation operations in the security field that is to detect abnormal situations, such as fires, floods, accidents and malicious behaviours such as thieves, illegal invasion. In this case of security, home automation integrated the subsystem that remote monitoring, alarms and emergency bells that can signal and respond to security conditions.

# 7. Algorithm Research

## 7.1. Exponential back-off algorithm

Exponential back-off is an algorithm that is usually used for network transport protocols to make sure that connection creation and data transport are stability and reliability. For instance, when the client is going to create a network connection, if the first creation fails, the client program should be waiting for t unit of times then re-try. If the creation still fails, the client program should be waiting for t1 unit of times then try again. The re-try should always continue until the client program connection creation timeout.

There is an exponential asymptotic trend between each time of back-off. More fails, then the longer back-off time should be. But if the conditions are reached up, the client would stop the behaviours.

## 7.2. Algorithm description

When network congestion and overload cause many devices or components in a network to generate errors. In this case, if the devices or components that were in errors continue sending data continuously, it is not only meaningless but also it will make the network more congested. We can suppose that simple case:

1. When the client sent a request to server fails.
2. Re-send a request after 0ms then it fails again.
3. Re-send a request after 10ms then it still fails.
4. Re-send a request after 20ms then it continuously fails.
5. Re-send a request after 40ms then it continuously fails again.
6. If that always fails after re-send N times, then $2^N$ x 10ms should wait for.
7. That will finish or quit when the conditions reached.

There is an accepted normally mathematical expression:

$$E(c) = \frac{1}{N+1}\sum_{k=0}^{N} k$$

The symbol c is the number of request times, and symbol N equal to $2^c - 1$. So, the equation can simplify to:

$$E(c) = \frac{1}{N+1}\sum_{k=0}^{N} k = \frac{1}{N+1} \times \frac{N(N+1)}{2} = \frac{N(N+1)}{2(N+1)} = \frac{N}{2} = \frac{2^c - 1}{2}$$

Finally, we can use equation $E(c) = \frac{2^c-1}{2}$ to describe the exponential back-off algorithm that calculates the expected back-off time of the mean of the possibilities.

## 7.3. Application scenario

The exponential back-off algorithm widely used in the LAN ethernet protocol IEEE 802.3 CSMA/CD standard that is sense the jam signals and collision signals of the network. Once detected, the delayed data transmission determined according to this algorithm, enhance communication stability and reliability.

At Home Automation, the communication and transmission of numerous devices are extremely dependent on the network. When the network is blocked, unstable, or even disconnected, it will inevitably cause fail to communicate between devices of home automation. How to ensure network work efficiently if there is a problem in the network, lower the frequency of device communication, drop the flow of data in the network medium, and thus reduce the network load. If it detects that the network is unable to communicate properly for a long time, it will send a warning message to the user in time. These are all possible with the exponential back-off algorithm.

Thereby, the exponential back-off is a critical technology that improves the quality of service in the network.

# 8. Ireland Policies Statement

## 8.1. Global Trends

At present, several major manufacturing countries in the world have independently formulated and development plans for dealing with the new industrial revolution. In the plans formulated by various countries, the policy of using artificial intelligence to replace human beings in production labour in the manufacturing industry is mentioned, which also marks the birth of the industrial Internet of Things(IIoT).

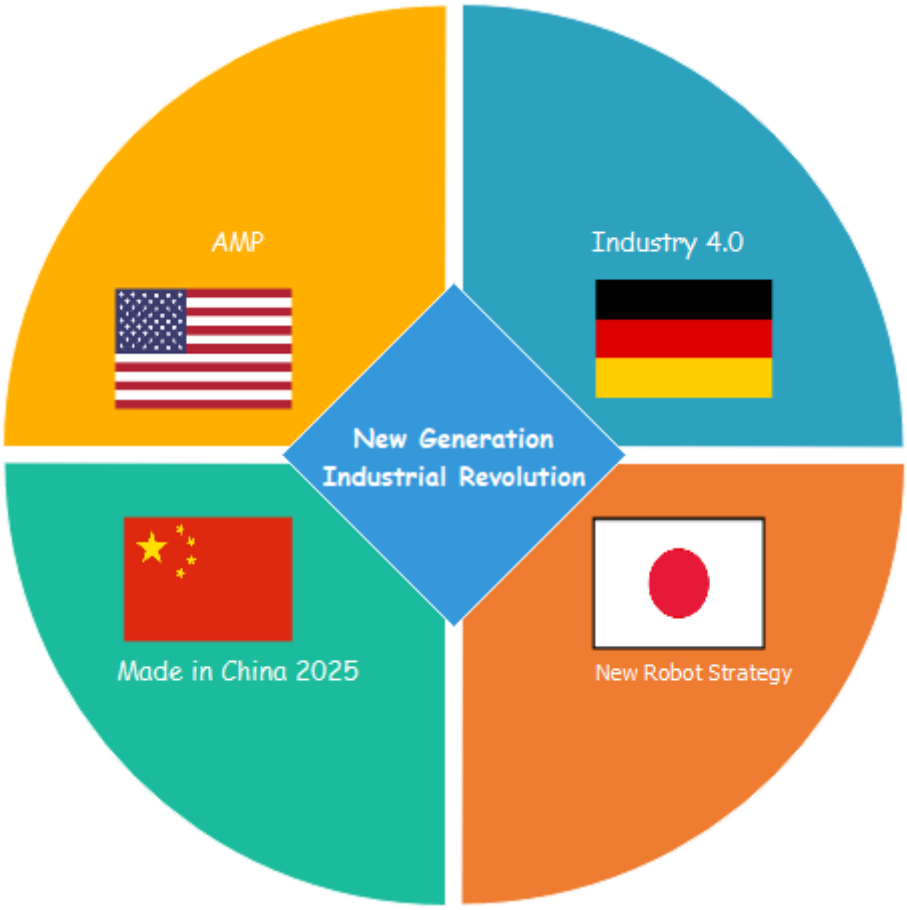


*Figure 37 Global Industrial Revolution*

For the Industrial Internet of Things, it contains the following key industries:

1. Energy utilization
2. Manufacturing factory
3. Medical health care
4. Logistics transportation

5. Home automation

## 8.2. Ireland Industrial Policies

Irish Manufacturing Research (IMR) team mentioned Manufacturing 4.0 that is the fourth industrial revolution. It is a collection of technologies that make machine manufacturing have the power of artificial intelligence to replace human production labour.

The government published the papers entitled "**Making It in Ireland: Manufacturing 2020**" (*Source: Dbei.gov.ie. (2019). Making it in Ireland: Manufacturing 2020.*) and "**Automation and Occupations Technical Paper**" (*Source: Igees.gov.ie. (2019). Automation and Occupations Technical Paper.*), demonstrates Ireland's manufacturing potential, will boost Irish manufacturing and revive the Irish economy, innovate with ICT and automation technology through factories, agriculture, healthcare, biopharmaceuticals and other industries.

The paper was published in 2013, entitled "**Future Skills Requirements for Manufacturing to 2020**" (*Source: Skillsireland.ie. (2013). Future skills requirements of manufacturing publication.*), mentioning the core skills needs of automation engineering to meet the challenges of the future automation industry in Ireland.

The paper of "**A Mapping of Smart Ageing Activity in Ireland and An Assessment of the Potential Smart Ageing Opportunity Areas**" (*Source:* Varnai, P. and Simmonds, P. and Farla, K. and Sharp, T. A. (2015). A Mapping of Smart Ageing Activity in Ireland and An Assessment of the Potential Smart Ageing Opportunity Areas.*)* published by the government that mentioned a lot of smart home industry. This paper is very clearly stated the opportunity areas included Assisted living, Adaptable housing, and Connected health.

According to Engineers Ireland report which entitled "Industry 4.0 – Manufacturing Industry in Ireland" that indicate the industrial policies:

***A. Awareness - building and collaboration***

- *Showcase digitalisation in manufacturing and generate media interest*
- *Join the international alliance 'Platform Industrie 4.0'*
- *Develop a national Industry 4.0 portal to provide information targeting SMEs*

***B. Education and re-skilling employees***

- *Develop education programmes on new areas in digitalisation*
- *Include data capture, analytics and critical evaluation in degree programmes*
- *Establish a structured Industry 4.0 Skillnet*

***C. Measures to support RD&I spend and capital investment required by manufacturing companies***

- *Ensure competitive financial terms for capital investment relating to Industry 4.0 are available to industry in Ireland*
- *Ensure industry in Ireland is deriving maximum value from European programmes*
- *Consider financial supports as applied in other Member States*

***D. Co-ordination and collaboration of activities across the national response***

- *Increase collaboration between research performing organisations*
- *Agree mechanisms of collaboration between EI, IDA, SFI and industry consortia*
- *Manage the co-ordination of national efforts through the Technology Centres*

(Source: *Engineersireland.ie. (2019). Engineers Ireland Industry 4.0 Policy Statement. p.2*)

# 9. Conclusion

## 9.1. Thinking of the future

We can imagine this scenario. There is a smart refrigerator in your home. Once you put all the food in the refrigerator, it automatically recognizes the barcode of each food and analyses the name, type, and nutrients of the food. When you are consuming these foods in the refrigerator, it will periodically release your diet to your mobile phone and guide you on how to eat properly to ensure a balanced diet. Before the refrigerator food is consumed, the refrigerator will send you a warning message to inform you and automatically combine you're eating habits to generate an order for the food need to purchase. Compare the price, freshness and other factors of the same food with different supermarkets. it automatically sends the order list to the best suitable supermarket through the internet. When the supermarket receives the order, the food purchased is automatically delivered to your backyard grass by the drone in smart logistics and then returned. You sort the food on the grass into the refrigerator. During the process of putting the food in the refrigerator, the refrigerator completes a record of the food name, type, and nutrients again.

Soon, we can find that our home environment is becoming smarter and more comfortable. We will rely on it just as we rely on air and water.

## 9.2. Home automation stages

Through the above research content, in the home automation system, 4 stages should be reasonably implemented below.

1. Connecting things & communication
2. Remotely controlling and monitoring them
3. Data Analytics & Business Intelligent
4. Data visualization

That involved key technical factor.

1. Sensor electronics
2. Communication standards and specifications
3. Intelligent electronic products
4. Cloud services
5. Big data analysis
6. Software development and integration

## 9.3. Home automation Challenges

Home automation can change people lifestyles and bring convenience to everyone, but it also poses a huge challenge to our technological development.

1. **Complexity**
   Different types of household appliances are abstracted through the software layer that establish a unified computing model. In this model, it is necessary to be compatible with the information interaction between people and devices, between devices and devices, between devices and surrounding environment, and so on. This is a very complicated computing model.

2. **Information security**
   Home automation brings convenience to life, but in fact it hides some serious problems, that is, information security and privacy issues. How to ensure the security of network communication, and the data is not intercepted and tampered with during transmission. Whether these security issues can be handled properly is the most concerned by many consumers.

3. **Scalability**
   There is a wide variety of household appliances and MEMS, different brands and different manufacturers. Even the same electrical appliances, due to different brands, different manufacturers, parameter specifications and standard protocols are not uniform. It is conceivable that integrating all home appliances in home automation, making them automated, intelligent, and able to scale as needed, all of those are challenges.

4. **The home appliance industry standards are not uniform.**

## 9.4. Further Research

The next about the functional specifications on home automation, for further research that should pay attention to the following aspects.

1. In-depth study of an open-source home automation system, understanding modules include the system design principles, communication specifications, and devices integration, control, as well as monitoring. Learn how these modules work together.

2. Understand the commonly used MEMS, its role, specifications, and how integrate into the home automation system.

3. Study the Raspberry Pi understanding how it works and what international standard protocols of LAN communication is adopted.

4. Learn mobile app development frameworks such as Flutter mentioned in this report that study how devices interact with the app.

5. Information security and privacy protected that involved network, firewall, VPN, MFA, encryption, GDPR etc.

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