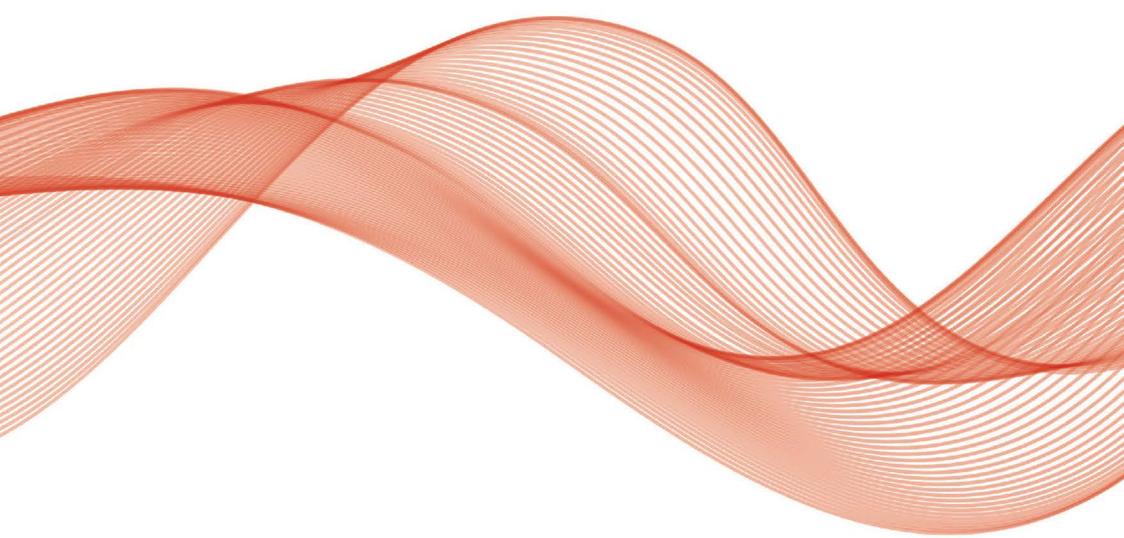

SECURING IOT IN INDUSTRY 4.0 APPLICATIONS WITH BLOCKCHAIN

Edited by
P. Kaliraj and T. Devi

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Contents

Preface

The Industrial Revolutions Industry 4.0 and Industry 5.0 are changing the world around us. Artificial intelligence and machine learning, automation and robotics, big data, Internet of Things, augmented reality, virtual reality, and creativity are the tools of Industry 4.0. Improved collaboration is seen between smart systems and humans, which merges humans' critical and cognitive thinking abilities with the highly accurate and fast industrial automation. The fourth and fifth Industrial Revolutions affect the roles that Indian universities and colleges prepare students for, and educational institutions are committed to helping produce the workforce for this new world and the student experience to match it.

Bharathiar University has designed guidelines for Curriculum 4.0 and has prepared new syllabi for all subjects intertwining Industry 4.0 and 5.0 tools onto various disciplines such as science, social science, arts, and education. The university has identified the gap in knowledge resources such as books, course materials, interdisciplinary curriculum, and innovative programmes. To fill this gap and to prepare the future pillars of our globe to face the volatile, uncertain, complex and ambiguous (VUCA) world, and to help the academic community, Bharathiar University has prepared guidelines for revising the syllabus, designing innovative faculty development programs, establishing connectivity to the real world for students, incubating creativity and inculcating design thinking. Moreover, with the active participation of all stakeholders under the esteemed leadership of the Honourable Vice-Chancellor, Prof. P. Kaliraj, interdisciplinary books are being edited for Education 4.0 and 5.0.

Technology has always played a crucial role in the lives of people over the decades. Industry 4.0, the current trend of automation, comprises smart factories, cognitive computing, cloud computing, augmented reality, the Internet of Things, and cyber-physical systems. Most countries are adopting this to attain higher levels in automation, operational efficiency, and productivity. Though it was proposed only for the manufacturing industry, today with billions of people and machines interconnected by powerful networks, it is essential that higher education curricula should be redesigned to match this change. Students should be made familiar with

Industry 4.0 tools and should learn how to apply the tools in the specific domains they live or work in. This book discusses the key components of Industry 4.0, which are the Internet of Things (IoT), blockchain, and cybersecurity.

The world today is driven by Industry 4.0 and is connected in every sense. The Internet of Things, or IoT, refers to the billions of physical devices around the world that are now connected to the Internet, all collecting and sharing data. After the advent of IoT, it is possible to connect everyday things to Internet. IoT makes everyday objects "smart" by enabling them to transmit data and automate tasks without requiring any manual intervention. Every day trillions and trillion bytes of data are generated by billions of devices connected to the Internet, so much that 90% of the world's data has been generated in the past couple of years. IoT also bridges digital and physical realities and supports information-driven automation. Physical devices such as sensors and actuators play a crucial role in IoT systems. With sensors, it is possible to collect data in almost any situation and hence they are widely used in various fields. IoT systems help in collecting and processing data at the same time. The collected data can be processed in real-time, which helps in optimizing the performance. This also helps in rectifying the malfunctions as early as possible. IoT has various advantages, such as ease of information access, communication capability, and cost-effectiveness. These advantages facilitate IoT to be utilized in various applications, such as smart cities, agriculture, industries, and healthcare. In this context, this book will unleash the roles of IoT, blockchain, and cybersecurity during this time of the fourth Industrial Revolution and their applications aligning with Education 4.0.

According to Fortune Business Insights, the global IoT market was valued at US$190 billion in 2018 and is projected to reach US$1,102.6 billion by 2026. This, in turn, will create a lot of job opportunities in IoT. It shows that there is a great need for educated individuals who have expertise in this domain. And with the demand for talented professionals more than doubling in the last few years, there are limitless opportunities for professionals who want to work on the cutting edge of IoT research and development. It is essential for universities and higher education institutions to offer a prescribed set of courses for a major or specialization in IoT. At the same time, those with dedicated IoT programs may have unique approaches to the discipline. This will create graduates who are skilled in IoT and this book can aid in imparting the concepts and knowledge of IoT among the graduates. This book provides a blend of IoT's fundamentals and applications with a description of its fundamentals, architecture, technologies for IoT, cybersecurity, and blockchain. This book provides relevant theory and industrial applications of IoT in various domains such as healthcare, smart farming, smart city, education, industries, cybersecurity, and blockchain.

What's in the Book?

Chapter 1 entitled "*Internet of Things*" describes how IoT has been widely used to improve the performance of industrial systems in the Industry 4.0 era. It provides an overview of IoT architecture and the technologies that enable IoT applications. This chapter provides a systematic understanding of the programming languages and tools used for IoT development and discusses the role of IoT in Industry 4.0 and the security issues involved in developing IoT applications.

Chapter 2 entitled "*IoT Applications in Education*" introduces technology related to higher education. The chapter gives a brief idea about the different approaches in higher education and the incipient higher education system. Further, it explains IoT applications in the teaching–learning process.

Chapter 3 entitled "*Industrial Internet of Things (IIoT) and Smart Industries*" provides an understanding of the Industrial Internet of Things (IIoT) and its impacts across industries, specifically in the insurance industry. Addressing the challenges and opportunities, the chapter provides a roadmap of IIoT in line with Education 4.0. This chapter is written by academicians.

Chapter 4 entitled "*Internet of M-Health Things (mIoT)*" elaborates how the state-of-the-art IoT is made use of in the medical field and how it helps to provide quality treatment to patients, even in the time of the COVID-19 pandemic. This chapter introduces an mIoT system that captures medical data in real-time remotely and stores it in the edge fog cloud. The mobile app introduced in this chapter assists patients in taking medicine on time and alerts them when vital parameter values fall below critical levels.

Chapter 5 entitled "*Industrial Internet of Things (IIoT) Applications*" presents the evolution of IIoT, the proliferation and market share, and some examples across major industries. Moreover, the chapter provides a learning plan for students embarking on the IIOT journey. This chapter is written by an industrial expert.

Chapter 6 entitled "*Smart Farming: IoT-Based Plant Leaf Disease Detection and Prediction Using Image Processing Techniques*" explores how smart farming is helpful for farmers to prevent plant diseases. It provides insights on enhanced product quality, volumes, cost management, waste reduction, and process automation. This chapter shows how plant diseases can be predicted using image processing techniques and how a smart farming system is beneficial to those farmers who are unable to get expert knowledge and advice.

Chapter 7 entitled "*Artificial Intelligence and the Internet of Things: The Smart City Perspective*" gives a detailed view of AI and IoT technologies and their relationship with the smart city applications that helps in building smart cities.

It also describes the layered architecture involved in the development of a smart city.

Chapter 8 entitled "*Internet of Nano Things: An Amalgamation of Nanotechnology and IoT*" delivers the general and the key notion of the Internet of Nano Things (IoNT), highlighting its significance and usefulness. The chapter provides an overall outline of the technology, including the nanomachine and nanonetwork architecture and nano-communication paradigms. The chapter also discusses the various applications of the Internet of Nano Things, along with a case study of nano biosensors for a better understanding of the reader.

Chapter 9 entitled "*Blockchain and Cybersecurity*" discusses how blockchains can enhance cybersecurity. This chapter details how blockchains can be used in cryptocurrencies, smart contracts, transferring financial instruments, Distributed DNS, Public Key Infrastructure, Certifying Authorities, anonymizing data in the healthcare industry, as repositories of public registers, IoT, traceability and supply chain management, public register of antiquities, etc.

Chapter 10 entitled "*Blockchain*" provides an overview of the structure and working of a blockchain. It also covers the types, evolution, benefits, and applications of blockchain to the Industry.

Chapter 11 entitled "*Cybersecurity*" proposes a framework of technologies designed to shield networks, computers, and data from malware, vulnerabilities, and unauthorized activities. This chapter teaches the experts to spot illegal activities, fend off attacks, and instantaneously respond to risks.

Chapter 12 entitled "*PLC and SCADA as Smart Services in Industry 4.0 for Industrial Automation Techniques*" explains the automation system employed in the industries along with its classification, functionality, flexibility, limitation, and application. It also explains how the PLCs and SCADA have been implemented for industrial applications, parameters, and their working. The working of Boiler Automation based on SCADA, programming, and data handling techniques between PLC, SCADA, and IoT are detailed.

How to Use the Book?

The method and purpose of using this book depend on the role that you play in an educational institution or in an industry or depend on the focus of your interest. We propose five types of roles: student, software developer, teacher, member of board of studies, and researcher.

If you are a student: Students can use the book to get a basic understanding of IoT, its tools and applications, cybersecurity, and blockchain. Students belonging to any arts, science, and social science disciplines will find useful information from chapters on IoT, cybersecurity, and blockchain. This book will serve as a starting point for beginners. Students will benefit from the chapters on IoT applications in *education, healthcare, industries, agriculture and farming, and smart city.*

If you are a software developer: Software developers can use the book to get a basic understanding of Internet of Things, its tools and applications, cybersecurity, and blockchain. Readers with software development background will find useful information from chapters on IIoT, IoNT, AI, and IoT. They will benefit from the chapters on *smart farming, smart city, Industrial IoT, Nanotechnology and IoT, and m-Health Things (mIoT).*

If you are a teacher: This book is useful as a text for several different university-level college-level undergraduate and postgraduate courses. A graduate course on IoT can use this book as a primary textbook. It is important to equip the learners with a basic understanding on IoT, a tool of Industry 4.0. The chapter on *Internet of Things* provides the fundamentals of IoT. To teach the applications of IoT in various sectors, say healthcare, teachers will find useful information from the chapter on *Medical Internet of Health Things (mIoT).* A course on IoT and cybersecurity could use this book, too.

If you are a member of the board of studies: Innovating the education to align with Industry 4.0 requires that the curriculum be revisited. Universities are looking for methods of incorporating Industry 4.0 tools across various disciplines of arts, science, and social science education. This book helps in incorporating IoT across science and education. The book is useful while framing the syllabus for new course that cut across IoT and disciplines of arts or science or social science education. For example, syllabi for courses entitled Internet of Things and Cybersecurity, Internet of Things in Science, and the Industrial Internet of Things may be framed using the chapters in the book. Industry infusion into the curriculum is given much importance by involving more industry experts – R&D managers, product development managers, and technical managers as special invitees in the board of studies. Chapters provided by industrial experts in this book will help infuse the application part of the IoT into the curriculum.

If you are a researcher: A crucial area where innovation is required is the research work carried out by universities and institutions so that innovative, creative, and useful products and services are made available to society through translational research. This book can serve as a comprehensive reference guide for researchers in developing experimental IoT applications. The chapters on the Industrial *Internet of Things, Smart Forming, Artificial Intelligence and the Internet of Things, Internet of Nano Thingsand Blockchain* provide researchers, scholars, and students with a base for research in the area of IoT.

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Acknowledgments

From Prof. P. Kaliraj

First and foremost, I express my sincere gratitude to **Hon’ble Shri. Banwarilal Purohit,** Governor of Tamil Nadu, India, who was instrumental in organizing the conference on Innovating Education in the era of Industry 4.0 during 14–15 Dec 2019 in Ooty, which paved the way for further work in Industry 4.0 knowledge world.

My heartfelt thanks go to Hon’ble Chief Minister of Tamil Nadu, India, and Hon’ble Minister for Higher Education, Government of Tamil Nadu. I thank Principal Secretary to Government, Higher Education Department, Government of Tamil Nadu.

I would like to express my thanks to Secretary to Governor, and Deputy Secretary to Governor, Universities Governor’s Secretariat, Raj Bhavan, Chennai.

I thank my wife, Dr. Vanaja Kaliraj, and family members for supporting and being patient.

From Prof. T. Devi

I record my sincere thanks to **Prof. P. Kaliraj**, Hon’ble Vice-Chancellor of Bharathiar University, who identified the knowledge world gap when the professor searched for a book on Industry 4.0 and triggered the process of writing and editing books in the Industry 4.0 series. His continuous motivation during the lockdown period due to COVID-19, sensitization, and encouragement are unmatchable.

I express my profound thanks to the vice-chancellor and registrar for the administrative support. Heartfelt thanks are due to the authors of the chapters for their contribution of chapters, continuous co-operation in improvizing the chapters as and when requested, and for timely communication. I thank all the expert members who served as reviewers for providing a quality and swift review.

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I thank my husband, Mr. D. Ravi; daughter, Mrs. R. Deepiga; son, Mr. R. Surya; son-in-law, Mr. D. Vishnu Prakhash; and grandson, V. Deera and family members for their encouragement and support.

*****

Editors

Prof. P. Kaliraj, Hon'ble vice-chancellor, Bharathiar University, a visionary and an eminent leader leading big academic teams has had more than three decades of teaching and research experience. He has held various renowned positions, such as officiating vice-chancellor of Anna University, head of the Centre for Biotechnology of Anna University, dean of faculty at A C College of Technology, and member of the syndicate for two decades at Anna University. Professor Kaliraj had research collaborations with the National Institute of Health in Maryland, USA; Glasgow University in Scotland, UK; and University of Illinois in Rockford, USA. University Grants Commission BSR Faculty Award and the Lifetime Achievement Award from the Biotechnology Research Society of India adorned the professor. **Forty-two scholars were gifted to receive the highest academic degree under his distinguished guidance**. **His remarkable patent in the area of filariasis is a boon in healthcare** and saving the lives of mankind. He is a great motivator and very good at sensitizing the faculty, scholars, and students towards achieving academic excellence and institutional global ranking. Professor Kaliraj is a recipient of the **Life Time Achievement Award and Sir J.C. Bose Memorial Award** for his outstanding contribution in higher education – research. (email: vc@buc.edu.in, pkaliraj@gmail.com)

Prof. T. Devi, PhD (UK), Professor, Centre for Research and Evaluation, former dean of research, professor and head, Department of Computer Applications, Bharathiar University focuses on state-of-the-art technology that industries adopt in order to make students ready for the future world. She is a **Gold Medalist** (1981–1984) from University of Madras and a **Commonwealth Scholar** (1994–1998) for her **PhD from the University of Warwick, UK**. She has three decades of teaching and research experience from Bharathiar University, Indian Institute of Foreign Trade, New Delhi, and University of Warwick, UK. Professor Devi is good in team building and setting goals and achieving them. Her research interests include integrated data modeling and framework, meta-modeling, computerassisted concurrent engineering, and speech processing. Professor Devi has visited the United Kingdom, Tanzania, and Singapore for academic collaborations. She has received various awards including **Commonwealth Scholarship and Best Alumni Award from PSGR Krishnammal College for Women (PSGRKCW), Proficiency award from PSG College of Technology and awards from Bharathiar University for serving for BU-NIRF, Curriculum 4.0, and Roadmap 2030 and guided 23 Ph.D. scholars.** Prof. T. Devi may be contacted at (email: tdevi@buc.edu.in, tdevi5@gmail.com)

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Chapter 1

Internet of Things

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Contents

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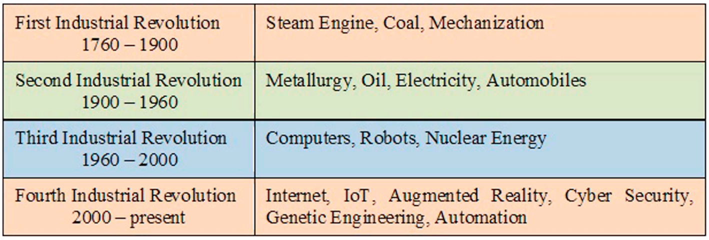
Objectives

After reading this lesson, the audience will gain knowledge of the following:

1. Fundamental concepts behind IoT
2. SComponents of IoT architecture
3. Technologies that enable IoT applications
4. Tools for IoT application development
5. Role of IoT in Industry 4.0
6. Security issues of IoT applications
7. Applications of IoT

1.1 Introduction

The advancements in technology have impacted every aspect of life over the decades (Nuvolari, 2019). The four Industrial Revolutions have a major role in the technological changes in society. The first Industrial Revolution started in the United Kingdom and slowly spread to various countries. The second Industrial Revolution started during the end of 19th century when



First Industrial Revolution 1760 – 1900	Steam Engine, Coal, Mechanization
Second Industrial Revolution 1900 – 1960	Metallurgy, Oil, Electricity, Automobiles
Third Industrial Revolution 1960 – 2000	Computers, Robots, Nuclear Energy
Fourth Industrial Revolution 2000 – present	Internet, IoT, Augmented Reality, Cyber Security, Genetic Engineering, Automation

Figure 1.1 Evolution of Four Industrial Revolutions.

industries started using lighter metals, alloys, and plastics. The ownership of the product of materials also got distributed. It was during this time that many countries moved to social realms. It was also during this revolution that oil and other energy resources were used widely. The third Industrial Revolution started in the 1960s when people started using nuclear energy as an energy resource. During the third Industrial Revolution only, electronics and computers started playing a vital role in almost all the processes of an industry. In early 2000, the fourth Industrial Revolution had begun which builds on the third Industrial Revolution. It was during this period that the Internet was widely used by almost all the people in the world. The revolution is currently changing the way people live and work. The technologies which contribute immensely to the fourth Industrial Revolution are augmented reality, big data and analytics, cloud computing, cybersecurity, Internet of Things (IoT), and robotics (Xu et al., 2018). The evolution of four Industrial Revolutions is shown in Figure 1.1.

One of the key technologies which is accelerating the current Industrial Revolution is the Internet of Things (Sathyan, 2020). Gartner has predicted that in 2020, 30% of communications with smart machines will be based on conversations with them. The main advantage of the usage of the technologies in the current industrial revolution is to produce things faster. Internet of Things helps in performing digital manufacturing quickly and perfectly. It intends to improve the performance of industrial systems. IoT will help in the collection of a large amount of data and help in the analysis of it, which would in turn help in revolutionizing the manufacturing industry. This chapter intends to provide the fundamentals of IoT that will help beginners intending to work with IoT. This chapter describes the architecture of IoT, technologies involved in developing IoT systems, applications of IoT, the role of IoT in Industry 4.0, and security in IoT.

1.1.1 Evolution of IoT

Research on making objects interact with each other has been happening since the 1970s. In 1982, programmers of Carnegie Mellon University had written software to connect to a Coke machine to check whether cold sodas were available so that they could go from their hostel rooms to purchase them. In 1990, John Romkey created a bread toaster that could be connected to the Internet to operate it. This device is considered the first IoT device. The device was presented at the October 1987 INTEROP Conference. In 1993, Quentin Stafford and Paul Jardetzky developed a coffee machine that could take pictures of the level of coffee three times per minute so that it could be monitored. In 1999, Kevin Ashton first used the term “Internet of Things” when he was working for Procter & Gamble Ltd. (Ashton, 2009). He used “Internet of Things” when he was making a presentation on radio-frequency identification (RFID). In 2000, LG Electronics Inc. developed its first Internet refrigerator. It had screens and trackers that could update the items that were available in the refrigerator. In 2002, a device called Ambient Orb was introduced by David Rose and his team from the Massachusetts Institute of Technology (MIT) Lab. The device could monitor the weather and other sources and could change its color. During 2003 and 2005 the term “Internet of Things” began to appear in a lot of publications including “The Guardian“ and “Scientific American”. RFID was mainly used in the United States (US) Department of Defense. In 2005, the United Nation’s International Telecommunications Union (ITU) released a write-up on “Internet of Things”. In 2005, a wireless fidelity (WiFi) enabled rabbit (Nabaztaz) was created by Rafi Haladijian and Olivier Manel. The device could talk about the stock market, news, and alarm clock. In 2008, the first International IoT Conference was conducted in Zurich, Switzerland. It was during this year only there were more IoT devices than people on earth. In 2008 only, the Internet Protocol for Smart Objects (IPSO) Alliance was established by a group of 50 companies including Google, Ericsson, Bosch, Intel, Cisco, and Fujitsu. The number of IoT devices including tablet PCs and smartphones were 12.5 billion, whereas the world population was only 6.8 billion. In 2008, IoT was declared as one of the “Disruptive Technologies” by the US National Intelligence Council. In 2011, IoT appeared on the ascending curve of the Gartner Hype cycle, and in 2014, it appeared on the peak of the Gartner Hype cycle. During 2014 and 2016, various products such as Google glass, Echo, and self-driving cars were developed. Various companies had started to develop many products. During 2017 and 2019, IoT product development was widely accepted. Various technologies such as artificial intelligence and blockchain were integrated with the IoT platforms. The various stages in the evolution of IoT are depicted in Figure 1.2.

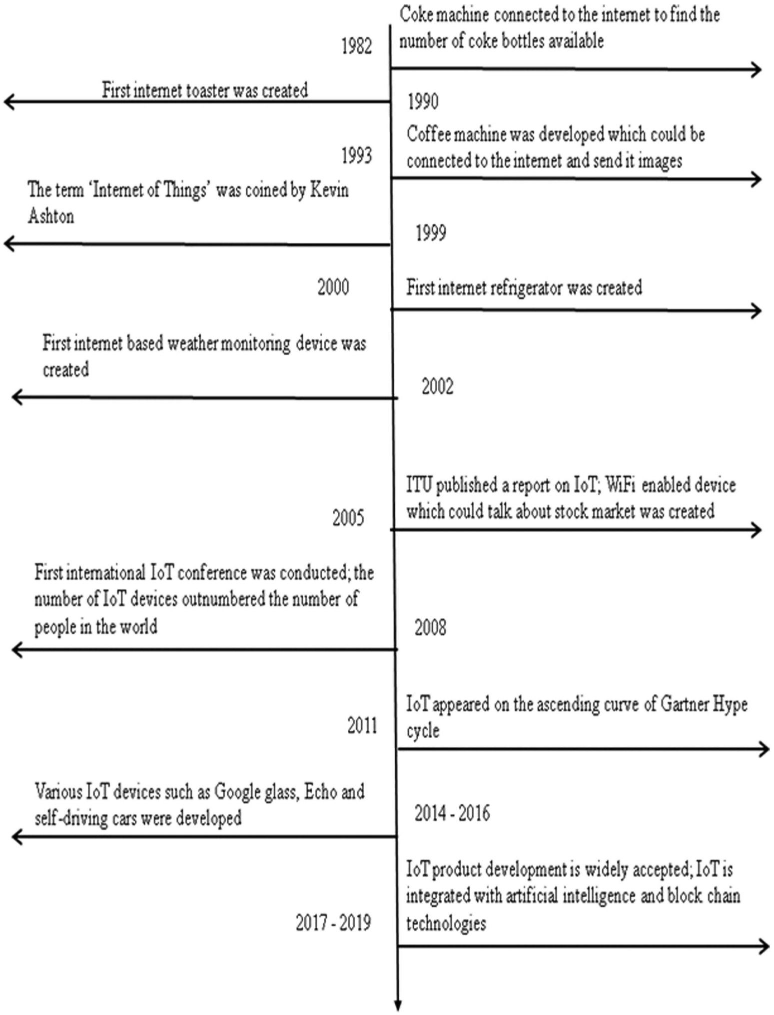


Figure 1.2 IoT Evolution.

1.1.2 Definition and Characteristics

IoT signifies a collection of devices that are composed of electronics, sensors, and software. They can communicate through the Internet. Security cameras, refrigerators, vehicles, and buildings are some examples of things that can communicate with each other using the Internet. Gartner defines "The Internet of Things (IoT) is the network of physical objects that contain embedded technology to communicate and sense or interact with their internal states or external environment" (Internet of Things, Gartner Glossary).

The Internet of Things has been defined in Recommendation ITU-TY 2060 as a "global infrastructure for the information society, enabling advanced services by interconnecting (physical or virtual) things based on existing and evolving interoperable information and communication technologies" (Recommendation of ITU-TY.2060, 2012).

Internet of Things exhibits certain characteristics (Martino et al., 2018), some of which are described below:

1. Connectivity: all the "things" or objects in IoT are connected to the cloud platform or server using the Internet. Sensors collect physical parameters which are sent through gateways to the cloud/server for further processing. Transfer of information happens for short distances or long distances using communication technologies such as WiFi.
2. Sensing: one of the important components of IoT systems is sensors that measure various physical parameters from other objects or the environment. The sensed data are then transmitted to the cloud or server.
3. Intelligence: IoT is a combination of hardware, software, and various algorithms that make the IoT objects respond to a particular situation in an intelligent manner. For instance, sensors in air conditioners sense the temperature and adjust the temperature accordingly.
4. Heterogeneity: IoT devices are used for various applications. They work in various hardware platforms, network connections, and software; hence, they are heterogeneous.
5. Voluminous data: Data plays an important role in IoT systems. Sensors collect data and send to cloud platform/servers, which are then processed and analyzed. There are several sensors connected to various IoT applications and all these sensors collect and transfer data at regular intervals. This causes a large volume of data from sensors to be sent to cloud platforms/servers where the data will be efficiently managed.

1.2 Architecture of IoT

IoT systems are built using sensors, actuators, and microcontrollers. It is a combination of various technologies (Ray, 2018). The typical three-layer architecture of IoT systems is depicted in Figure 1.3. The three layers of the architecture are as follows:

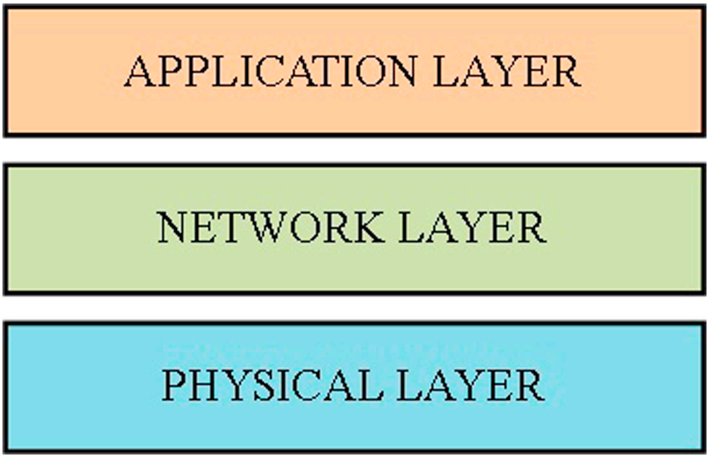


Figure 1.3 Three Layer Architecture of IoT Systems.

1. Physical Layer: It has sensors and components that are responsible for obtaining data and converts them to digital format. This layer also identifies other smart objects in the environment.
2. Network Layer: It connects the objects in the physical layer with servers. It is used for transforming the data obtained from the sensors. In some IoT systems, this layer also processes the sensor data.
3. Application Layer: It is responsible for performing specific user services. This layer determines the application of IoT including smart homes, smart healthcare, smart metering, and smart transport.

1.2.1 Physical Devices

IoT systems consist of devices such as sensors, actuators, and other data transmission devices (Rayes and Salem, 2019). The main use of sensors is to take measurements of changes from their surroundings and send the data to actuators or applications that will further process the data. Depending on the types of signals generated by the sensors they are classified as digital and analog sensors. The output generated by analog sensors is continuous whereas the output generated by digital sensors is discrete. The various physical parameters measured by the sensors are sound, heat, motion, and biochemical parameters. Some of these sensors are described below:

1. Acoustic sensors: These sensors help in measuring the sound. An example of a device that uses an acoustic sensor is microphone. The ultrasonic vibration sensor has also an acoustic sensor embedded in it.

2. Gyroscope sensors: These sensors help in calculating the orientation and angular velocity of an object. The sensor can measure even very meager changes in the orientation of the objects. Angular velocity is defined as the change in the rotational angle of the object per unit of time.
3. Humidity sensors: These sensors help in measuring the amount of humidity available in the air or soil. These sensors are categorized as capacitive, resistive, and thermal. All three categories can measure even small changes in humidity.
4. Temperature sensors: These sensors help us in measuring the temperature of an object or environment. These sensors are categorized as resistive or thermocouple sensors. A thermometer is an example of a device that has temperature sensors in it. Temperature sensors are also available in air conditioner systems.
5. Pressure sensors: These sensors help in measuring the force applied to the sensors. These sensors are categorized as capacitive and piezo-resistive pressure sensors. They can be indirectly used to measure the flow of water, air, and altitude.
6. Proximity sensors: These sensors help in identifying objects that are near the sensors without any physical contact. They emit electromagnetic radiation such as infrared waves and wait for the waves to hit the object and return. There are various types of proximity sensors such as photoelectric, passive, radar, sonar, and ultrasonic sensors. They can be used in parking systems, conveyor systems, touch screens, and roller coasters.
7. Image sensors: These sensors covert the light into an electrical signal so that it can be converted to an image, viewed, and analyzed. For instance, vision cameras have image sensors inside them.
8. Light sensors: These sensors sense light energy and convert it to an electrical signal. Light sensors can detect various wavelengths of light ranging from infrared to ultraviolet rays. Some types of light sensors are phototransistors and photodiodes. Light sensors are used in smartphones, automobiles, and shipment cargos.

Actuators are devices that convert electrical energy into mechanical energy. Usually actuators make use of the data collected and analyzed by the sensors. Some of the actuators are described below:

1. Thermal actuators: These actuators convert thermal energy into mechanical energy. An increase in the temperature causes an object to expand and a decrease in the temperature causes it to contract. Examples of thermal actuators are bi-metallic strips that are used in micro thermostats.

2. Electrical actuators: These actuators are a type of gear motor that converts electrical energy into mechanical torque. Electrical line actuators cause linear motion. Rotary electrical actuators are digital current (DC) motors and alternating current (AC) motors.
3. Hydraulic actuators: These actuators utilize hydraulic power generated by compressing liquid. The hydraulic power is converted to mechanical energy by the actuators. The hydraulic actuators generate linear or rotary motion. Examples of hydraulic actuators are hydraulic jacks.

The physical layer also consists of hardware platforms which are mostly microcontrollers. Sensors are often connected to microcontrollers directly. Microcontrollers in IoT systems utilize their computational power to manipulate the data. Sometimes, if there is no need for processing the data, they just send it to the cloud/server through a gateway for processing. Some of the microcontrollers are given in Figure 1.4 and are described below:

1. Arduino Uno: This microcontroller depends on an ATMega328P processor for computation. The processing speed is 16 MHz and operates at 5 V. It has a flash memory of 16 KB and RAM of 1 KB. It supports a number of input/output (I/O) pins, out of which 14 are digital I/O and 6

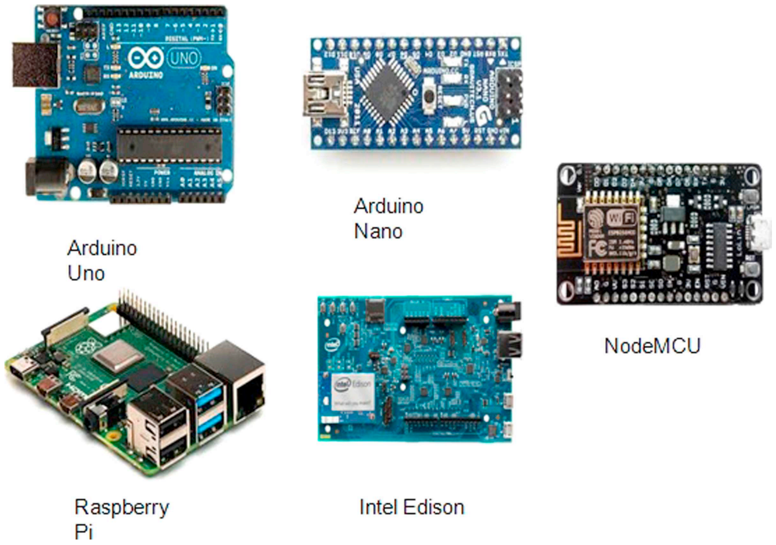


Figure 1.4 Sample Microcontrollers.

are analog I/O. It is able to communicate with a computer by sending and receiving data through an USB cable.

2. Arduino Nano: It is the smallest microcontroller which is based on an ATMega328 processor. It works at 5 V and the processing speed is 16 MHz. The size of its flash memory is 32 KB and that of SRAM is 2 KB.
3. Raspberry Pi: It is an open-source and miniaturized computer which runs on Linux. The usual model of Raspberry Pi has a processing speed of 700 MHz. It has 512 MB of RAM. The latest version of Raspberry Pi is Pi 4. The latest model has built-in WiFi and Bluetooth. It has 40 general-purpose input/output pins.
4. Intel Edison: It is developed by Intel. The initial version had a processing speed of 100 MHz with an operating voltage of 3.3V. It has a flash memory of 4 GB. The processor is Intel Quark SOCX 1000. The latest model supports Bluetooth and WiFi.
5. ESP8266 NodeMCU development board: It is an open-source IoT development kit that runs on ESP8266 WiFi SOC from Espressif Systems. It has a processing speed in the range of 80–160 MHz. It has 128 KB of internal RAM and 4 MB of external flash memory. It supports an 802.11b/g/n WiFi transceiver. It has 17 general-purpose input/output pins. These pins may be connected to peripheral interfaces including Analog to Digital Converter (ADC) channel, Universal Asynchronous Receiver Transmitter (UART), Serial Peripheral Interface (SPI), and Inter-integrated circuit (I2C) interface.

1.2.2 Gateways and Networks

Gateways are hardware or software that connect the microcontrollers and sensors with a cloud platform/server (Kang and Choo, 2018). Some sensors generate little data while others generate thousands of data per second that are collected and transferred by the gateways. They gather the information transmitted from various sources and interfaces and communicate that to the cloud. The gateway transfers data in both directions and takes care of the security of the data. Gateways are the glue for connecting all devices in IoT systems.

The data obtained using sensors have to be transmitted to the Internet through a smart gateway. Typically IoT devices connect using Internet protocol (IP) networks, which require power and memory (Montori et al., 2018). Sometimes IoT devices connect locally using Bluetooth and RFID. Some of the communication technologies viz., Wireless Fidelity (WiFi), IPv6 over Low Power Wireless Personal Area Network (6LoWPAN), Low Power Wide Area Network (LoraWAN), Bluetooth, and Zigbee are described below:

1. Zigbee: It is an IEEE 802.15.4 standard developed by Zigbee Alliance and mainly support wireless networking. It is useful for low data rates and short-range transmission. The data transmission range is 10–100 m.
2. Bluetooth: It is an IEEE 802.15.1 standard used for wireless transmission. It is also used for short-range data communication. The advantage of Bluetooth is that it requires low power for operation. One of the drawbacks of traditional Bluetooth is that it cannot directly connect to the Internet and an intermediate node is required. Hence, Bluetooth Low Energy (LE) was introduced, which provides quick communication using connectionless medium access control (MAC).
3. LoWPAN: It is a wireless personal area network that supports IPv6. It refers to IPV6 over Low Power Wireless Personal Area Network. It provides end to end data transfer using IPv6 and can provide a connection to various types of networks.
4. WiFi: It is the IEEE 802.11x standard and is most commonly used for connecting IoT devices to the Internet. It is useful for short-range data transmission and can connect to several networks. The power consumption is also less for WiFi. The communication range is 50–100 m.
5. LoRaWAN: It is mainly used for long-range data communication. The main advantage of LoRaWAN is to provide inter-operability across various networks. It has low power consumption and provides wide network coverage. The communication range is 5–10 km.

1.2.3 Edge Analytics

Traditionally all data collected from sensors were transferred to the cloud, where it will be processed and analyzed. For large applications, transmitting all the information obtained from the sensors to the cloud is cumbersome. In recent times, there is an increase in the use of edge analytics. In edge analytics, data is processed and analyzed in the gateways that are physically attached to the sensors. Hence, gateways store, process, and analyze the data instead of transferring it to the cloud. This makes the processing and analysis of data near the user. In some cases, the data is monitored and if it is in the normal range or if the data does not tell any significant information then, it is stored and processed in the edge devices. Otherwise, if the data is not in the normal range or if further processing is required to cull out information from the data then the data is pushed to the cloud. Cisco, Intel, and other companies have developed gateways to perform edge computing. IoT edge analytics is depicted in Figure 1.5.

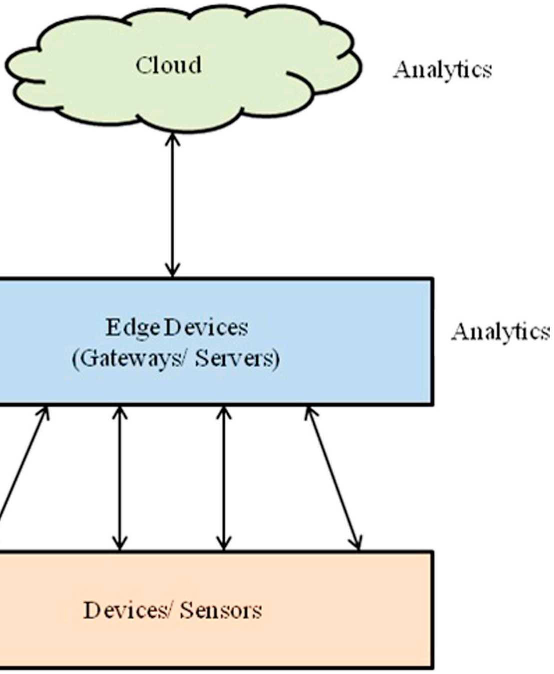


Figure 1.5 IoT Edge Analytics.

1.2.4 Fog Computing

Edge computing helps in saving time and bandwidth by making the computation in edge nodes present near sensors, rather than blindly pushing the information to the cloud. Similarly, fog computing helps in bringing the computational capability in the processors attached to local area networks (LANs) of sensors. So, the computational devices in fog computing are further away from the sensors or actuators compared to edge computing (Elazhary, 2019). Fog computing has features that resemble either edge computing or cloud computing. The advantages of fog computing are low latency, mobility of processors, and lesser transmission capacity. In fog computing, the processing is distributed, which is useful in applications such as environmental monitoring using large-scale sensor networks. Some of the challenges in adopting fog computing include management of Quality of Service (QoS) and security and regulatory requirements. The interface supported by fog should be able to provide interactivity with the cloud and sensors.

1.2.5 Cloud Platforms

Cloud platforms provide services for data storage, visualization, processing, data analysis, and decision making (Ray, 2016). These cloud platforms should be able to capture all the information created by billions of IoT systems in the world. Several vendors offer various cloud services that use advanced algorithms to perform predictive analysis. Cloud services for IoT are offered in three ways viz., Infrastructure as a Service (IaaS), Software as a Service (SaaS), and Platform as a Service (PaaS). The IoT cloud platform is different from the conventional cloud platform. The conventional cloud platform provides a pool of hardware and software resources to be available to all users. The IoT cloud platform offers services to process the real-time data coming from a variety of IoT systems. Some of the IoT cloud platforms are summarized in Table 1.1.

1.2.6 IoT Data Analytics

There are several sensors capturing data continuously which results in lots of data being transferred for storage in cloud platforms (Adi et al., 2020). The data collected are heterogeneous as they are collected by various types of sensors such as temperature, gyroscope, humidity, pressure, proximity, image, and light sensors. The data collected from sensors are raw. They have to be analyzed to interpret the information and take necessary actions. To analyze the information present in the sensor data various machine learning (Majumdar et al., 2021; Zhang et al., 2020) and artificial intelligence (Zhang, 2020; Greco et al., 2020) techniques have been used in several research works. Every day, more and more IoT devices are being used by people which leads to an increase in the data created and transmitted them. Cloud platforms enable the storage of large amounts of data. The usage of artificial intelligence based techniques helps in the extraction of correlation or features from data and prediction of future data. The usage of IoT data analytics helps in (a) identifying the platforms available in the pas data; (b) predicting the data in near future based on the collected data; (c) recognizing correlations among different types of data collected for an application; and (d) suggesting actions to be taken for a particular pattern in the data.

1.2.7 IoT Data Visualization

IoT systems generate a lot of data from sensors which have to gather and analyzed for various purposes. To interpret the information or to identify correlations present in the analyzed data correctly, it is necessary to display the data properly. In some situations, multiple visualizations of the same data help

Table 1.1 Sample Cloud Platforms

IoT Cloud Platform	*Website*	*Services Offered*	*Cost*
Xively	https://xively/com/	Data capture and visualization	Free
ThingSpeak	https://thingspeak.com	Data capture, visualization, and analytics	Free
ThingWorx	https://www.thingworx.com/	Data capture, visualization, and analytics	Pay per use
Amazon IoT	https://aws.amazon.com/iot/	Data management, analytics, visualization, and device management	Pay per use
Oracle IoT Cloud	https://www.oracle.com/Internet-of-things/	Data management, analytics, and visualization	Pay per use
IBM Watson IoT Cloud	https://Internetofthings.ibmcloud.com/	Data monitoring, visualization, analytics, and device management	Pay per use
Google IoT Cloud	https://cloud.google.com/iot-core	Device management, data management, visualization, and analytics	Pay per use
Microsoft IoT Cloud (Azure)	https://azure.microsoft.com/en-in/services/iot-hub/	Communication between IoT devices and device management	Pay per use
Cisco IoT Cloud Connect	https://www.iotone.com/software/iot-cloud-connect/	Data management and device management	Pay per use
General Electric Predix	https://www.ge.com/digital/iiot-platform	Data monitoring, analysis, and event management	Pay per use

to interpret the data from various dimensions. The data from sensors is presented in various forms such as bar/pie charts, histograms, graphs, and heat maps. Some of the challenges in the visualization of IoT data are (a) selection of right visualization and (b) appropriate display of heterogeneous and voluminous data coming from various sensors (Peddoju and Upadhyay, 2020). Hence it is essential to develop application-specific dashboard design that helps to visualize data to allow the users to gain insights from the data.

Several IoT data visualization tools are available globally. PowerBI (www.powerbi.microsoft.com) is based on Azure cloud-based services and provides several visuals based on the data. It supports both real-time streaming and offline data. Some versions of Microsoft PowerBI are free to use. Grafana (www.grafana.com) is a web application that supports the visualization of data, particularly time-series data. It is based on open-source software. Its dashboard is dynamic and supports several data sources. Kibana (www.elastic.co/kibana) is another popular open-source visualization tool for IoT data. It has a web-based user interface for viewing huge volumes of data in various forms such as bar/line charts, scatter plots, and maps. Tableau (www.tableau.com) is yet another interactive tool to visualize IoT data. It provides support for connection with servers such as Cloudera Hadoop and Amazon Aurora. It provides support for a wide range of charts apart from providing mapping functionality. The Tableau Public version is available for free to use. Thingsboard (www.thingsboard.io) is another open-source visualization tool. It provides various visualizations for both offline and real-time data. It supports IoT protocols such as Message Queuing Telemetry Transport (MQTT) and Constrained Application Protocol (CoAP) for device connectivity.

1.3 Technologies for IoT

1.3.1 Communication Protocols

Protocols that belong to the application layer of IoT architecture are essential for the transfer of data in IoT systems (Dizdarevic et al., 2019). These protocols ensure that there is no packet loss and low packet response time. They also should be able to support a wide variety of IoT devices and heterogeneous data. They should also support lightweight communication. Some of the IoT application layer protocols are described below:

1. Constrained Application Protocol (CoAP): This protocol is mainly used in low power and constrained networks. It is based on user datagram protocol (UDP). It is motivated by HyperText Transfer Protocol (HTTP)

Table 1.2 Summarization of IoT Protocols of Application Layer

Characteristics	*CoAP*	*MQTT*	*XMPP*
Transmission	UDP	TCP	TCP
Messaging	Request/ Response	Publisher/ Subscriber	Request/ Response
Security	DLTS	SSL	SSL
QoS	Supported	Supported	Not Supported
Open Source	Supported	Supported	Supported

and Representational State Transfer (REST) architecture is used. It supports asynchronous communication. The Datagram Transport Layer Security (DTLS) is used by CoAP to support integrity, security, and privacy.

2. Message Queuing Telemetry Transport (MQTT): This protocol is mainly used in constrained devices and unreliable networks. It is based on a publisher/subscriber client that uses Transmission Control Protocol/ Internet Protocol (TCP/IP). Hence, it supports reliability during message transmission. MQTT supports three Quality of Service (QoS) levels and the message is encoded using the Secure Socket Layer/Transport Layer Security (SSL/TLS) protocol. It supports asynchronous communication.
3. Extensible Messaging and Presence Protocol (XMPP): This protocol transfers data over the distributed network based on TCP. One of the biggest advantages of XMPP is that it is extendable. It depends on Extensible Markup Language (XML) technology and offers communication between client–client, client–server, and server–server. These protocols are summarized in Table 1.2.

1.3.2 Wireless Sensor Networks

Wireless sensor networks (WSNs) are part of IoT systems. Wireless sensor networks are wireless networks of a collection of sensors to monitor the physical parameters of the environment and pool the data to a single system/server to process and analyze the data (Kocakulak and Butun, 2017). The three main components of wireless sensor networks are nodes (sensors), gateways, and users. These components of WSN are shown in Figure 1.6. Nodes or sensors are connected and they transmit data through a gateway. The gateway and the users

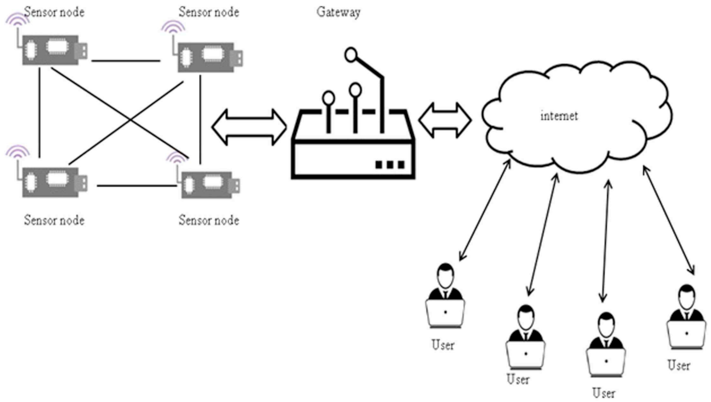


Figure 1.6 Typical Architecture of WSN.

are connected using a common network or Internet. All nodes in a WSN sense and collect information regarding a particular physical parameter from the environment such as temperature.

One of the main characteristics of the nodes in IoT systems is that they are connected to the Internet. The sensor nodes in WSNs have to be connected to the Internet so that they can be part of IoT systems. This can be achieved in various ways. Two of these methods are described here. In the first method, the entire WSN is connected to the Internet through a gateway. In the second method, individual sensor nodes in the WSN are connected to the Internet through separate gateways. In the first method, there is a single gateway and hence the entire network can fail if there is a problem in the gateway. This problem does not occur in the second method.

1.3.3 Cloud Computing

Cloud computing and IoT are increasingly being used in all aspects of life in recent years (Botta et al., 2016). Cloud computing is the usage of various computing services on a pay-per-use mode. The user cannot directly manage these resources. There are two categories of working models of cloud. The first category is called the deployment model which defines how the cloud is accessed. The deployment model is further classified as public, private, hybrid, and community cloud. In the public cloud, the services may be accessed easily by the general public such as email services. In the private cloud, the services may be accessed by a specific organization only and hence the security is also severe in this type. Hybrid cloud has the characteristics of both private and public cloud where important activities are carried out using private cloud and non-important activities are carried out using the public cloud. In the community cloud model, the services can be accessed by a group of organizations. Based on the reference models of the cloud, it is categorized as Infrastructure as a Service (IaaS), Platform as a Service (PaaS), and Software as a Service (SaaS). IaaS allows access to resources such as machines and virtual storage. PaaS allows access to runtime environments and tools. SaaS allows access to software applications. With the help of cloud computing, users can use any required hardware and software for a specific time without the need to install the hardware and software.

Cloud computing is the access to data and software from a centralized pool by consumers. IoT systems support communication between devices through the Internet. Both cloud computing and IoT support each other. A lot of data is generated by IoT systems which are transmitted to the cloud. When the user uses the resources in cloud computing, he has to pay only for the resources used. This characteristic is very useful for small IoT-based companies who want to reduce the overall costs. IoT developers also make use of the collaboration provided by cloud computing.

1.3.4 Embedded Systems

In today's world, embedded systems are found in almost all electronic equipments. These systems consume very little power and are used in almost all devices such as remote controls, digital cameras, microwave ovens, digital video disc (DVD) players, washing machines, and air conditioners. Applications of embedded systems include healthcare, automobiles, home automation, networking, and robotics. Embedded systems are part of a larger application that perform specific tasks. The major components of an embedded system are microprocessor or microcontroller, memory, networking components, and input/output units. With the advancements in very large-scale integration (VLSI), small chips come with enormous computation power and memory. The characteristics of embedded devices such as low power consumption and small size are very much suitable for IoT systems. Mostly, embedded systems can be programmed using languages such as C, C++, and Java.

IoT systems integrate microprocessors, memory, sensors, actuators, and communication (Serpanos and Wolf, 2018). Hence, embedded systems are part of IoT systems that enable a lot of IoT applications. Some of the computations of IoT systems can be performed by the microcontrollers themselves. The decision of whether the computation should be done at the embedded device or in other higher layers should be based on the type of computation, the energy status of the embedded device, and other parameters. With the powerful technological advancements in embedded systems, they will play a major role in computing, making it reside in the edge devices.

1.4 Developing IoT Applications

An IoT developer should be aware of a lot of domains such as networking, cloud programming, hardware device programming, and security. IoT development involves assembling the hardware devices; programming the devices which receive the data and send them to the server; programming the cloud/server to process the data and store it; and providing the data in an easily understandable manner by using appropriate visualization techniques. The languages and tools used should be specific to the domain of the IoT solution.

1.4.1 Programming Languages for IoT Devices

IoT systems are made up of three types of devices viz., sensors/actuators which generate data; gateways which organize them; and cloud/server which collect and process the data. Some of the popular languages used for programming IoT solutions are described below:

1. C: It is one of the popular languages used for programming the physical layer i.e., the hardware devices. It is widely used for programming constrained devices.
2. Java: It is another popular language used by developers for programming non-desktop systems. The application is developed on a desktop and then moved to a chip with Java Virtual Machine (JVM). Other editions of Java, such as Java Micro Edition or Java ME, are also used for programming embedded devices.
3. Javascript: It is one of the popular languages for IoT applications. The processing done in servers/gateways can be written using Javascript. The hubs and sensors that use Linux can also execute Node.js. Espruino and Tessel are some of the microcontrollers that can execute Javascript.
4. Python: It is a widely popular language used for coding IoT devices. Even microcomputers like Raspberry Pi, which runs on a Linux operating system, uses Python. It is used in several domains. Various versions of it, such as microPython, are also developed. Some of the Python packages used for IoT development are JSON, XML, HTTPLib, URLLib, and SMTPLib.
5. Swift: It is one of the popular languages used for developing Apple iOS and macOS applications. If the devices in IoT systems have to communicate with iPhone or iPad, then Swift is the choice.

1.4.2 Integrated Development Environments (IDEs) for IoT Development

Integrated Development Environment (IDE) is software with a coder editor, debugger, and automation tools that help developers to develop software applications. There are many IoT applications today, and this has led to the development of a lot of IDEs for working with these applications. Some of the IDEs used for IoT application development are described below:

1. Arduino IDE: Arduino is an Italy-based company that develops microcontroller boards and kits. It has developed the Arduino IDE to work with the microcontrollers. It has all preloaded libraries required to work with simple IoT applications. It supports C and C++ programming languages.
2. Raspbian: Raspbian is an operating system with the IDLE IDE to work with Python language. It is one of the environments suitable to program the Raspberry Pi device. Raspberry Pi is not just a microcontroller; it is a "microcomputer". It has lots of packages and precompiled libraries to work with Raspberry Pi devices.
3. PlatformIO IDE: PlatformIO is an open-source IDE that is cross-platform and supports a debugger. It supports various development boards, platforms, and frameworks. It provides an "intellisense" code editor for C and C++ programming languages. It has thousands of libraries to work with embedded devices.
4. Eclipse IoT IDE: It is an open-source IDE created by Eclipse Foundation for working with IoT applications. It has lots of tools and runtimes for IoT computing. In particular, an open-source development framework called Eclipse Kura is used for IoT application development. Eclipse Kura is based on the Java programming language.

1.4.3 Tools for IoT Development

The development and management of IoT applications are quite complex. Some tools are available to make these jobs easier. One of the advantages of these tools is that the IoT applications need not be built from scratch. Some of the tools used for developing IoT applications are described below:

1. NETCONF-YANG: Network Configuration Protocol (NETCONF) is based on a simple network management protocol (SNMP). NETCONF stores the details of its configuration and state using YANG, which is a data modeling language. The NETCONF-YANG tool helps in the

management of IoT systems by providing various features such as management Application Programming Interface (API), transaction and rollback managers, data model manager, and configuration API.

2. Puppet: Puppet is a popular tool that helps in managing the configuration of IoT systems. It helps in maintaining the servers, storage, and networks in IoT systems. All the operations in Puppet are carried out using resources such as services, processes, files, and users.

1.5 Applications of IoT

There are many IoT applications that are used in the day-to-day life of all people and industries. Apart from improving the lives of people, IoT systems have found applications in various domains such as transportation, healthcare, agricultural, industrial, and environmental domains. Some of the applications of IoT are represented in Figure 1.7.

1.5.1 Agriculture

With the rise in population, there is a huge demand for a multifold increase in food production in terms of quantity and quality in food (Tzounis et al., 2017). IoT systems are used to capture the images of plants to monitor plant diseases. Plants are cultivated in greenhouses where the climatic conditions have to be maintained at particular levels. Monitoring the climatic parameters in greenhouses is possible

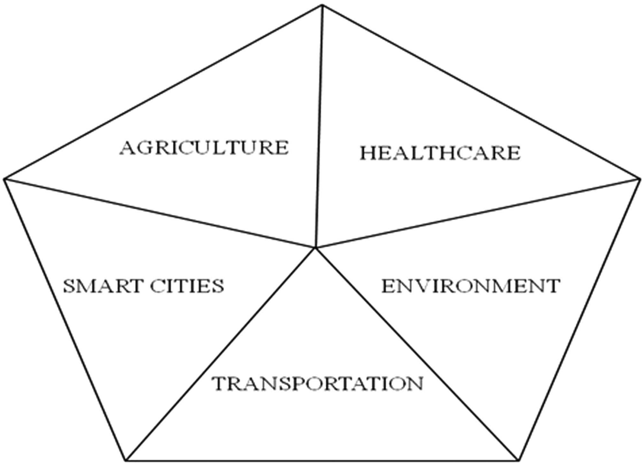


Figure 1.7 Applications of IoT.

through IoT systems. Sensors such as optical sensors and humidity sensors have been used to find the temperature and moisture content in the agriculture fields. The information is then utilized to control the amount of water used for irrigation. Wireless sensors have been used for tracking animals, monitoring them, and analyzing their behavior. RFID tags have been used for tracking agricultural products, thus enabling automation in the food supply chain.

1.5.2 Smart Cities

The number of cities is increasing globally every year. Smart cities are intended to make urban life easier by applying smart systems to the infrastructure and services of the city. IoT systems will help the buildings in the cities to efficiently utilize resources such as energy and water (Alavi et al., 2018). Sensors and smart grid technologies are utilized to make use of resources such as water and electricity appropriately to avoid wastage of these resources. Similar smart systems and innovative ideas are used to promote business employment which improves the economy of smart cities. These systems will help in monitoring the collection and disposal of garbage in the cities. IoT-based smart grids help in smart metering to optimize electricity consumption and billing. IoT also helps in controlling the traffic in roads of smart cities by learning the traffic patterns and controlling traffic appropriately.

1.5.3 Transportation

The number of private vehicles is increasing, which has led to an increase in traffic. IoT-based systems have been implemented to obtain information related to the location of vehicles, their routes, and traffic congestion, which in turn can help in the reduction of traffic and provide information related to travelers (Patel et al., 2019). IoT-based systems are implemented to schedule the vehicles in the routes to reduce the traffic congestion in the city. IoT-based traffic management systems also help in altering the traffic among various routes to facilitate the movement of emergency vehicles such as ambulance of vehicles of VIPs. IoT-based systems also help in monitoring accidents or various events happening on roads. The data obtained about these events can help in providing various services to people affected by accidents or to people participating in the events. Pressure sensors in IoT systems automatically find whether seats in a vehicle are occupied by a person or whether it is empty so that it can be allotted to another person.

1.5.4 Environment

Appropriate disposal of waste and its maintenance is essential to avoid polluting air, water, and oil. Pollution of air, water, and oil can be prevented with the help of IoT systems (Hart and Martinez, 2015). Sensors are used to monitor the quality of air all over the city throughout the year. pH in water is used to determine the quality of water and the health of aquatic animals in the water. Sensors are used to collect the data related to radiation levels near nuclear facilities to detect the leakage of nuclear energy. Sensors may also be fixed at places like electric poles and trees to monitor the levels of radiation in the city. Sensor-based IoT systems can be implemented to detect disasters such as floods, storms, volcanic eruptions, earthquakes, and other natural disasters. Once these disasters are detected, they can be communicated to people so that they can move to safe places. Sensors are used to monitor the glaciers so that any calamities can be predicted earlier. Sensors are used to monitor the temperature, which is important for the growth of roots and absorption of nutrients. Sensors are also used to monitor the moisture level of the soil to ensure the proper growth of plants.

1.5.5 Healthcare

With the rise in the human population and the average lifespan of people, there is a lot of demand from healthcare for providing better treatments. IoT has revolutionized the healthcare sector, making it move towards Healthcare 4.0 (Aceto et al., 2020). IoT helps in the remote monitoring of patients. Similarly, sensors and wearables help in monitoring the physiological signals of people at regular intervals so that their health status can be checked. These sensors and wearables can be used for patients who are in intensive care units or for any healthy people who want to have a regular check-up. Currently, various physiological signals such as temperature, electrocardiogram (ECG), glucose level, oxygen saturation, pulse rate, and pressure levels can be monitored. Recently, fog computing at gateways provides various healthcare services such as storage and analysis of healthcare data (Mutlag et al., 2019). IoT systems also help elderly people in taking appropriate medicines at the correct time. Examples of such systems include implantable insulin pumps.

1.6 Industrial IoT (IIoT)

IoT has invaded our everyday lives and has linked physical objects to the digital world, supporting communication between these objects (Lampropoulos et al., 2019). IoT has also found applications in industries particularly in intelligent manufacturing which is referred as the Industrial Internet of Things (IIoT). Industry 4.0 is associated with a highly automated, integrated, and efficient manufacturing environment. In every aspect of manufacturing, intelligence is incorporated which leads to the development of smart factories. With the integration of sensors, actuators, networking technologies, and storage systems, it is possible to monitor and control every process involved in industrial manufacturing. The IIoT services and applications can appropriately schedule and control the manufacturing operations. Moreover, the IIoT systems can communicate with the help of devices. It is possible to track the assets of the factory wherever it is transported. Hence, it is possible to monitor and manage all the processes such as procurement of raw materials, production, transport, and monitoring the finished products.

Although the incorporation of IoT in manufacturing has made the processes involved in manufacturing efficient, there are also some challenges (Khan et al., 2020). Some of the challenges are the enormous amount of data, the heterogeneous nature of IIoT systems, and the complex and decentralized processing of data. Efficient data management policies have to be considered for the transmission and storage of data. These policies should take into consideration the heterogeneous nature of IIoT systems. IIoT should also support wireless technologies.

1.7 Security in IoT

One of the challenges of IoT applications is the security issues associated with IoT systems. In IoT every object will be able to communicate with each other; hence, there is a need for security that is different from the traditional web applications (Kouicem et al., 2018). Moreover, the characteristics of IoT systems such as mobility of the objects, wireless communications, diversity of connected devices, and scalability of the IoT make security mandatory for IoT systems. Security challenges are present in every layer of IoT architecture, including application-based layer, network-based layer, and device-based layer.

Security solutions of the application-based layer include the usage of Datagram Transport Layer Security (DTLS), secure application proxy, password verification, secure coding, usage of file signatures, the establishment of a secure communication channel with authentication, and usage of lightweight encryption schemes. Similarly, security solutions of the network-based layer include the definition of timestamp and authentication parameter for packet verification, usage of encryption-based signatures, installation of threat hunting modules such as intrusion detection system (IDS), and usage of lightweight encryption systems. Security solutions of the device-based layer include measurement of signal strength, computation of the number of packets delivered, encoding packets, and usage of an appropriate intrusion detection technique.

1.8 Summary

In recent years, IoT has enabled people and/or things to be connected anytime and anywhere using the Internet. It offers various applications in various domains such as agriculture, environment, healthcare, smart cities, and transportation. In particular, IoT helps in automating the processes involved in industries. Industrial IoT will definitely impact the lives of people due to its role in factory automation to automotive connectivity. This chapter provided the fundamentals of IoT that will be useful to naïve users of IoT. This chapter described the architecture of IoT, technologies involved in developing IoT systems, and applications of IoT.

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