ENABLING THE INTERNET OF THINGS

FUNDAMENTALS, DESIGN, AND APPLICATIONS

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Preface

Objectives

The emerging paradigm of Internet-of-Things (IoT) plays a consequential role to improve almost all aspects of human life, i.e. domestic automation, transportation, education, health, agriculture, industry, etc. The simple conception of IoT as a network of identifiable connected smart things is fundamentally based on the integration of various diversified technologies including pervasive computing, sensor technology, embedded system, communication technologies, sensor networking, Internet protocols, etc. for the provisioning of intelligent computing services. In our experience we have noticed that although the simple idea of IoT is easy to comprehend, at the undergraduate level, students are unable to describe the importance and placement of IoT components in an IoT system. This book tries to provide the basic, precise, and accurate demonstration of IoT building blocks as well as their role in various IoT systems. The objective of this book is to provide a good starting point for undergraduate students who have basic prior knowledge of Internet architecture. At an abstract level, this book is an effort to partially fill the gap associated with the understanding of IoT concepts through the designing of the IoT system prototypes in Packet Tracer. We believe that after implementing IoT system prototypes in Packet Tracer, students will find it easier to grasp complete details of IoT systems.

Key Feature

Concerning the building of IoT foundations, this book can be used as a textbook at the undergraduate level. The key feature of this book is that it targets core aspects of IoT and provides its readership a better perspective both in terms of basic understanding of IoT technologies as well as the designing of IoT systems in Packet Tracer. To the best of our knowledge, this book can be considered as the first attempt to design simple IoT systems using Blockly programming language.

Audience

This book is suitable for undergraduate students enrolled in the IoT course. This book assumes that the reader has a good understanding of Computer Networks and basic programming concepts. Students are comprehensively facilitated in this book to explain IoT essentials besides the guidance of designing IoT systems in Packet Tracer.

Approach

At the end of each chapter, review questions in the form of case studies have been asked to explore students' clarity about IoT concepts discussed in that particular chapter. In this book, the design and implementation of IoT systems at an abstract level are presented in Blockly language.

Organization of the Book

To address the issues related to the understanding of IoT fundamentals at the undergraduate level, this book is structured as follows:

Chapter 1 is exclusively written to introduce the evolution, vision, definition, characteristics, enablers, architectures of the IoT paradigm, and its distinction from other related technologies. This chapter builds the foundation for the understanding of IoT systems and is considered a prerequisite for the following chapters.

The primary focus of Chapter 2 is to establish an understanding of the IoT building blocks along with the necessary details related to various IoT hardware and software technologies. Besides, this chapter also provides a concise design and implementation perspective of IoT systems in Packet Tracer.

The contents of Chapter 3 are oriented along the lines of sensing principles and understanding of various aspects related to the design and implementation of wireless sensors and sensor networks. The layer-level functionality of wireless sensor networks in this chapter explains the effective communication requirements of sensors in IoT systems.

Chapter 4 describes the basics of IoT gateways in terms of its architecture and functionalities. In addition, this chapter also elaborates how IoT gateways having advanced features of data filtering and analytics support Edge computing and how Edge computing-based solutions provide benefits to specific IoT-based real-life applications.

Chapter 5 discusses the mapping of IoT protocols to layered IoT architecture and provides in-depth details of various infrastructure, service discovery, and application layer protocols of IoT protocol stack in terms of their functionality and usage in a real-life scenario.

Chapter 6 focuses on the description and explanation of components and employment of Cloud and Fog architectures in different IoT systems.

Chapter 7 introduces real-life application domains (i.e. domestic automation, smart transportation, smart agriculture and farming, smart manufacturing and industry automation, energy conservation, etc.) where the IoT technologies play a vital role to improve the standard of human life through the automation of these systems.

In Chapter 8, the classification of IoT attacks, as well as constraints and requirements of IoT systems, are discussed. Moreover, the discussion about security threats at each layer of IoT architecture is also the part of this chapter.

Chapter 9 illustrates the nature of social relationships between IoT devices, explains the functionality of the components of social IoT architecture, and provides an understanding of the applicability of social aspects of smart devices in IoT applications.

Chapters 10 and 11 are devoted to the design and implementation details of IoT projects in Packet Tracer exploiting constructs of Blockly programming language.

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1

Internet of Things (IoT) Fundamentals

LEARNING OBJECTIVES

After studying this chapter, students will be able to:

- describe the evolution of the IoT concept.
- state the vision and definition of IoT.
- explain the basic characteristics of IoT.
- distinguish the IoT from other related technologies.
- elaborate the IoT enablers.
- explain the IoT architectures.
- articulate the pros and cons of IoT.
- apply the IoT architecture concepts for specific IoT applications.
- understand the implementation aspect of IoT architecture.

1.1 Introduction

In our daily lives, the augmented practice of Information and Communication Technologies (ICT) plays a paramount role in the development of emerging information societies. In developed countries, ICT is being employed to develop various innovative applications and services to address the challenges of sustainable societies, thus improving the quality of human lives. In the modern era, a plethora of things are being connected to each other using underlying network technologies with an aim to promote the paradigm of the Internet of Things (IoT). IoT is a network of uniquely identifiable connected *things* (also known as devices, objects, and items) offering intelligent computing services [1]. Things in IoT are also known as Smart Things that provide feasibility in performing the execution of daily life operations in a rational way. Moreover, IoT also positively assists the communication process among human beings. IoT comprises diversified technologies including pervasive computing, sensor technology, embedded system, communication technologies, sensor networking, Internet protocols, etc. which eventually underpin the economic growth of modern societies. The fundamental notion behind IoT is the provision of seamless ubiquitous connectivity among things and human beings. The basic idea of IoT

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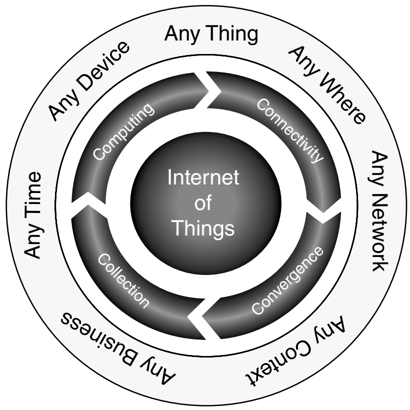

Figure 1.1 The concept of As and Cs in the IoT.

can be conceived as a representation of various As and Cs, as shown in Figure 1.1 [2]. In Figure 1.1, the As reflect the concept of ubiquity or globalization (i.e. any device, anywhere, anytime, any network etc.) and the Cs mirror the main characteristics of IoT (i.e. connectivity, computing, convergence, etc.). IoT, in essence, can be seen as an addition of the third dimension named "Thing" to the plane of ICT world, which is fundamentally based on two dimensions of Place and Time as shown in Figure 1.2. This "anything" dimension ultimately boosts the ubiquity by enabling new forms of communication of humans and things and between things themselves [3].

1.2 Evolution of IoT Concept

The concept of ubiquitous computing through smart devices dates back to the early 1980s when a Coke machine at Carnegie Mellon University was connected to the Internet and able to report its inventory of cold drinks [4, 5]. Similarly, Mark Weiser in 1991 [6] provided the contemporary vision of IoT through the terminologies of ubiquitous computing and pervasive computing. Raji in 1994 elaborated the concept of home appliance automation to entire factories [7]. In 1999, Bill Joy presented *six web* frameworks wherein device-to-device communication could be formed [8]. Neil Gershenfeld in 1999 used a similar notion in his popular book *When Things Start to Think* [9]. In the same year, the term "Internet of Things" was promoted by Kevin Ashton during his work on Radio Frequency Identification (RFID) infrastructure at the Auto-ID Center of Massachusetts Institute of Technology (MIT) [10]. In 2002, Kevin was quoted in Forbes Magazine with his saying "We need an *Internet for things*, a standardized way for computers to understand the real world" [11]. The article was entitled as *The Internet of Things*, which was the first-ever official document with the use of this term in a literal sense.

The evolution of IoT with reference to the technological progress in Internet conception is shown in Figure 1.3. The typical Internet introduced in the early 1990s was only concerned with the generation of static and dynamic contents on the World Wide Web (WWW). Later on, large-scale production and enterprise-level business

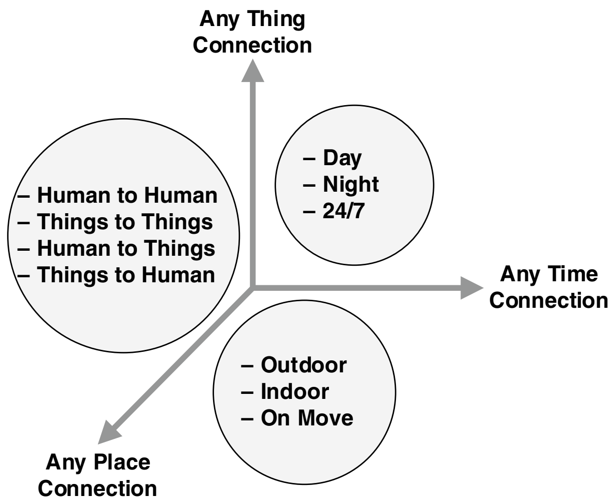

Figure 1.2 Thing as a new dimension to endorse IoT. Source: Peña-López [3].

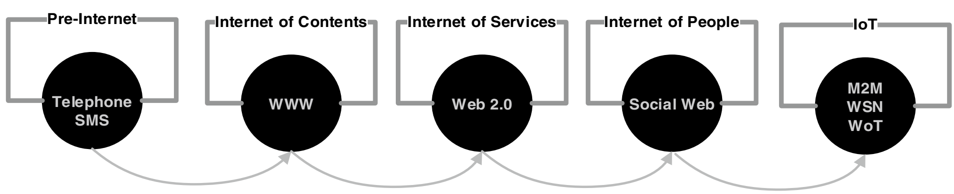

Figure 1.3 Technological progression in IoT.

collaborations initiated the creation of web services which laid the foundation of Web 2.0. Nevertheless, with the proliferation of affordable smartphones and tablets, social network apps become dominant on the Internet. In current situation, advancements in embedded system, Machine-to-Machine (M2M) communication, Cyber Physical Systems (CPS), Wireless Sensor Network (WSN), and Web of Things (WoT) technology enabled the communication of things over the Internet. The overall technological progression related to IoT is shown in Figure 1.3.

1.3 IoT Vision

The conventional WWW offers the convenience of information searching, e-mail conversation, and social networking. The emerging trend of IoT comes up with a vision of expanding these abilities through interactions with a wide spectrum of electronic appliances. In general, the IoT vision can be seen in terms of things centric and Internet centric. The things-centric vision encompasses the advancements of all technologies related to the notion of "Smart Things." On the other hand, the Internet-centric vision involves the advancement of network technologies to establish the connection of interactive smart things with the storage, integration, and management of generated data. Based on these views, the IoT system can be seen as a dynamic distributed network of smart things to produce, store, and consume the required information [12]. The IoT vision demands significant advances in different fields of ICT (i.e. digital identification technology, communication technology, networking technology, computing technology, and distribution system technology), which are in fact the enabling technologies or fundamental elements of IoT [13, 14]. More specifically, the IoT paradigm can be envisioned as the convergence of three elementary visions, i.e. Things-oriented vision, Network-oriented vision, and Semantic-oriented vision [15, 16]. This convergence of three visions with abilities and technologies is shown in Figure 1.4.

Things-oriented vision at the initial level promotes the idea of things network through unique identifiable Electronic Product Code (EPC). Things-oriented vision in the present form is evolved into smart sensor networks. In Internet-oriented vision, Internet Protocol for Smart Object (IPSO) communities is formed to realize the challenging task of smart sensor communication. Considering unique identification through Internet Protocol (IP) addressing, IPSO communities are working for the interoperability of smart things (having sensors) to IP protocol technologies. Finally, the Semantic-oriented vision provides the solution to deal with the huge amount of data generated by the IoT devices. IoT architectural layers and associated protocols have been structured in these three envisions [17].

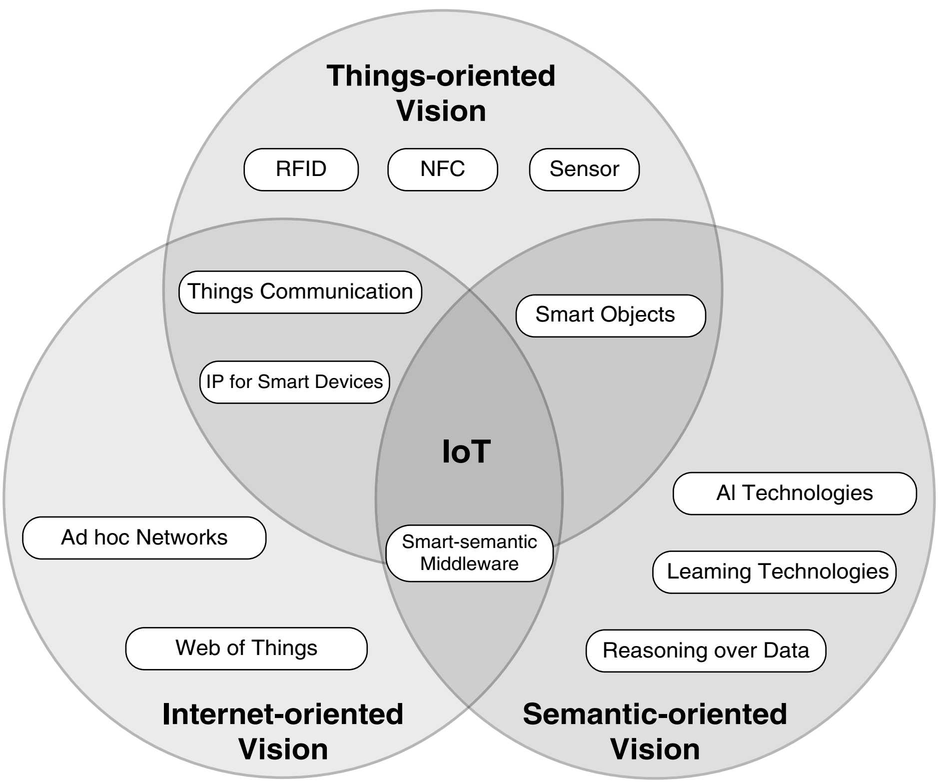

Figure 1.4 IoT as convergence of three visions. Source: Adapted from Atzori et al. [15].

1.4 IoT Definition

Considering the facts of similarity with peer technologies and envision the convergence of three different visions, it is not an easy job to provide a precise definition of IoT. In simple words, IoT could be deemed as a system wherein things are connected in such a manner that they can intelligently interact with each other as well as to humans. However, to better comprehend IoT, a number of standard organization and development bodies have provided their own definitions [13, 15, 18, 19]. A few IoT definitions presented by different standard organizations are illustrated in Table 1.1 [20].

Table 1.1 IoT definitions by standard organizations.

Standard organization	IoT definition
Institute of Electronic and Electric Engineering (IEEE)	"The Internet of Things (IoT) is a framework in which all things have a representation and a presence in the Internet. More specifically, the IoT aims at offering new applications and services bridging the physical and virtual worlds, in which Machine-to-Machine (M2M) communications represents the baseline communication that enables the interactions between Things and applications in the Cloud."
Organization for the Advancement of Structured Information Standards (OASIS)	"System where the Internet is connected to the physical world via ubiquitous sensors."
National Institute of Standards and Technology (NIST)	"Cyber Physical systems (CPS) – sometimes referred to as the Internet of Things (IoT) – involves connecting smart devices and systems in diverse sectors like transportation, energy, manufacturing, and healthcare in fundamentally new ways. Smart Cities/Communities are increasingly adopting CPS/IoT technologies to enhance the efficiency and sustainability of their operation and improve the quality of life."
International Standard Organization (ISO)	"It is an infrastructure of interconnected objects, people, systems, and information resources together with intelligent services to allow them to process information of the physical and the virtual world and react."
Internet Engineering Task Force (IETF)	"In the vision of IoT, "things" are very various such as computers, sensors, people, actuators, refrigerators, TVs, vehicles, mobile phones, clothes, food, medicines, books, etc. These things are classified as three scopes: people, machines (for example, sensor, actuator, etc.) and information (for example, clothes, food, medicine, books, etc.). These 'things' should be identified at least by one unique way of identification for the capability of addressing and communicating with each other and verifying their identities. In here, if the 'thing' is identified, we call it the 'object'."
International Telecommunication Unit (ITU)	"IoT is type of network that is available anywhere, anytime, by anything and anyone."

1.5 IoT Basic Characteristics

Considering all perspectives of modern-day IoT systems, a few generic and vital characteristics are shown in Figure 1.5 and explained in Table 1.2 [21, 22].

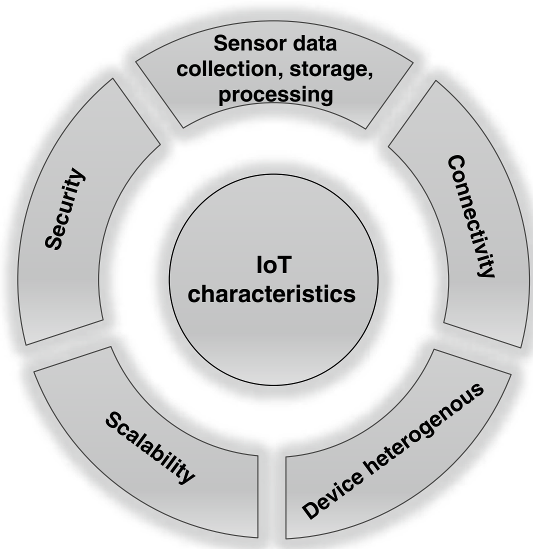

Figure 1.5 Fundamental IoT characteristics.

Table 1.2 Description of fundamental characteristics of IoT.

IoT characteristic	Description
Sensor Data Acquisition, Storage, Filtering and Analysis	The plethora of distributed Sensors (or smart things) gather observation of physical environment/entity and direct to Cloud for storage and analytics with an ultimate objective to improve business workflow
Connectivity	IoT has made possible the interconnectivity of Physical and Virtual things with the help of the Internet and global communication infrastructure (that is built using wired and wireless technologies)
Device Heterogeneity and Intelligence	The interoperability of devices (based on different hardware and network platforms) with the provisioning of ambient intelligence at the hardware/software level supports intelligent interactions
Scalability	The plethora of IoT devices connectivity shifts human interactions to device interactions
Security	The security paradigm is required to be implemented at the network level as well as the end-devices level to ensure the security of data

1.6 IoT Distinction

From the evolutionary perspective of IoT, it seems that IoT in different eras has been regarded as another name of a particular technology. Therefore, the term IoT is associated with other technologies in literature, i.e. embedded system, M2M communication, CPS, WSN, and WoT. However, the IoT concept is not attributable to any single technology.

1.6.1 IoT Versus Embedded Systems

Table 1.3 shows the differences between embedded systems and IoT.

1.6.2 IoT Versus M2M

Table 1.4 shows the differences between M2M and IoT.

1.6.3 IoT Versus CPS

CPS and IoT are highly overlapped; therefore, it is very difficult to demarcate the boundary between their differences. Both IoT and CPS encompass embedded devices that are able to transmit physically sensed data over the network. However, the use of these terms has been exploited by different communities on the basis of perceived criteria. Table 1.5 shows the differences between CPS and IoT.

Table 1.3 Difference between embedded systems and IoT.

Embedded system	IoT
Embedded systems include electronic devices that are usually standalone in nature and independently run on the Internet	IoT is a system that includes Internet connectivity-reliant devices for communication
Embedded systems are a combination of hardware and software (firmware)	IoT systems are a combination of computer hardware, software, and networking capabilities that are embedded into things of our daily lives
Embedded systems firmware mostly needs no modifications once the device is delivered to the clients	IoT requires continuous update
Example: ECG machine in a healthcare service that analyzes health parameters associated with humans is an example of embedded systems	Example: ECG machine connected to the Internet and able to transfer human health parameters on a remote server is an example of IoT devices
Embedded systems are a subset of IoT	IoT is a broader term including different technologies, i.e. embedded systems, networking, and information technology