Chapter 1

Internet of Everything: A Unifying Framework Beyond Internet of Things

Ergin Dinc
University of Cambridge, UK

Murat Kuscu
University of Cambridge, UK

Bilgesu Arif Bilgin
University of Cambridge, UK

Ozgur Baris Akan
University of Cambridge, UK

ABSTRACT

In this chapter, the authors put forward the notion of internet of everything (IoE) as an effort to maximally connect our communication infrastructure to the universe, which can itself be regarded as the real IoE, an interconnected network of physical phenomena (i.e., Everything we perceive as independent wholes that persist through time, such as molecules, light, waves, living organisms, and celestial objects, with the purpose of gaining better understanding of its mechanisms and manipulating them to enable novel technologies via a networked sensing, analysis, and actuation approach). The strategy to outline the IoE effort is by dissecting the vast IoE landscape into IoXs according to their various application domains (Xs), for each of which the authors give an up-to-date account of the state-of-the-art in related fields and point out the challenges in contemporary research faces. They also discuss a wide spectrum of challenges and future research directions (e.g., ubiquitous connectivity, security, big data, etc., which are common to many IoXs and penetrate into the IoE effort in general).

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INTRODUCTION

In this age of enlightenment, our understanding of the universe grows rapidly with an accelerating rate. We now understand that universe is a vast, but nevertheless connected, entity whose evolution is described by a set of rules, the laws of physics. It is empirically apparent that these rules give rise to recurrent, i.e., persisting through time, shapes within the universe, which we observe and label as entities such as light, electrons, nuclei, molecules, living creatures, planets, stars, galaxies etc, i.e., everything we distinguish as persistent carriers of information. These laws of physics we formulate, apart from trying to explain the existence of everything, serve at the same time as protocols of communication between these information carrying entities. Thus, our description of the universe can, and should, be regarded as a theory for an INTERconnected NETwork of EVERYTHING we perceive. In short, the universe from our perspective is the INTERNET of EVERYTHING (IoE). However, the quest for establishing a coherent understanding of this IoE requires, as is well known, the probing of it by means of methods within our grasp, i.e., our technology. In this regard, the technological term IoE, i.e., the concept of expanding our INTERNET, INTERconnected NETwork of computers, to EVERYTHING, actually stands for the effort of expanding our technology and infrastructure to match as much as possible to the IoE that is the universe and to gain control over it. This effort, the vision of IoE, therefore, is that of connecting our already developed infrastructure to all the various entities we observe within this universe, and now on we will mean by IoE our effort of connecting to everything there is.

For achieving this vision, we start by dissecting the vast IoE landscape into IoXs according to their various application domains (Xs), e.g., Nano Things (NT), People and Senses (PS), Sensors (S), Agricultural Things (AT), Money (M), Energy (En), Vehicles (V), Battlefield Things (BT), Industrial Things (IT), and Space (Sp), and analyze each IoX effort in itself. Careful observation and contemplation show that any IoX effort, or in general IoE, will have the four components that it relates to, namely people, things, processes and data. At its origin, as being a human effort IoE contains people at its center. People are observers of their surroundings, and from human cognitive perspective the first thing identified are the objects, referred mostly as things. By primitive empirical observation we see some things around us are in motion, and more careful analysis, called science, shows us that actually everything is in motion, according to some set of rules, which we try to decipher. We refer to isolated coherent motion of things distinguishable from their surrounding as processes. Finally, we translate our observations of various processes around us into our own language and call it data. Thus, naturally, each IoX will contain these four components. Each of these components have a natural relationship with each other, as symbolically depicted in Figure 1.

Realization of the IoE framework demands highly interdisciplinary approaches to overcome unique connectivity, interoperability and energy-efficiency challenges mainly resulting from the close interaction between cyber and physical worlds and the interaction between machines (e.g. machine-to-machine (M2M) communication), and the enormous number of interconnected entities. The things and the people are interconnected anytime and everywhere within the IoE framework, implying a challenge for ubiquitous connectivity. Heterogeneous characteristics of technologies and services connected to each other require a high level of interoperability for seamless operation, which in turn calls for the design of novel interfaces, including those between bio-cyber domains. Bandwidth scarcity stands as a major challenge due to the huge number of connected entities, and calls for novel solutions, such as the upgraded cognitive radio techniques and the use of new frequency bands. Devising communication techniques orthogonal to electromagnetic (EM) communication, such as molecular communications,
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