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# Collaborative building of behavioural models based on internet of things

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ABSTRACT

This paper proposes a new framework that takes advantage of the computing capabilities provided by the Internet of Thing (IoT) paradigm in order to support collaborative applications. It looks at the requirements needed to run a wide range of computing tasks on a set of devices in the user environment with limited computing resources. This approach contributes to building the social dimension of the IoT by enabling the addition of computing resources accessible to the user without harming the other activities for which the IoT devices are intended. The framework mainly includes a model of the computing load, a scheduling mechanism and a handover procedure for transferring tasks between available devices. The experiments show the feasibility of the approach and compare different implementation alternatives.

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## 1. Introduction

The proliferation of Radio Frequency IDentification (RFID), Wireless Sensor Network (WSN) [1], and smart mobile technologies, among others, in a communicating-actuating network creates the Internet of Things (IoT), wherein sensors and actuators blend seamlessly into the environment around us, and the information is shared across networks [2]. The increase in the computing capabilities of these devices turns them into intelligent objects that can cooperate with each other to build distributed and autonomous ecosystems. This evolution creates cyber-physical systems that are beyond the interconnection of individual things and can provide joint and collaborative services.

The number of small computers in a user environment is increasingly large in the IoT paradigm. In a typical IoT scenario, user computers and devices usually fall into two categories, sometimes diffuse: (1) general purpose computers, designed for a wide diversity of tasks (i.e. laptops and desktop computers), and (2) specific purpose devices (i.e. wearables and smartphones). Computers falling into category (1) often have a variable computing resource availability depending on the dynamic load imposed by user activities. On the other hand, devices in (2) are intended to be used basically for specific applications and data capture. However, advanced applications arise, targeting to those devices (2), which require ever greater computing resources. Here we have, for example, the new virtual reality, gaming and health applications. These complex new applications can exceed the computing resources of the devices and produce delays and malfunctions. In these cases, the user devices quickly become obsolete and users must acquire more powerful devices in order to run the applications properly.

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This situation identifies the main challenge for the research carried out here. The proposal defines a collaborative processing framework to overcome this issue by sharing the application tasks among the available devices in the user environment. This approach is especially useful for critical applications such as health applications. In those domains, the systems do not provide high availability features but more than one unit can be used to improve the probability of accurately capturing a given variable and, therefore, a set of available devices can be operational in the users surroundings.

The main technical contribution of this work consists of the method described which allows for interaction and the distribution of the running of the applications among the IoT objects. As scientific contribution, this work proposes a formal framework wherein the performance and computing resource aspects of distributing the computation among a set of computers are specified. Moreover, the scheduling criteria is described on the basis of these specifications. The novelty of this work lies in considering the set of devices around the user as a cyber-physical system for collaborating in the computation of tasks. In addition, the orientation of the model to the area of healthcare creates a realistic working environment in which to implement the ideas for a social collaborative IoT.

The rest of the paper is organized as follows: First, we present a brief review of related research areas and their relevant architectural solutions. Then, we approach our framework by formally defining the problem and providing a conceptual view of the solution. After that, we address the experimental design and testing, where we verify the feasibility of the key framework elements. Finally, we draw the relevant conclusions and identify future directions for this research.

## 2. Related work

The following two subsections discuss the state-of-the-art of using the IoT paradigm for e-Health applications and data gathering from biosensors and other devices to perform computations. There are many research groups focussing their work on some of the topics covered in this work, which shows its significance within the scientific community and society as a whole. Only those most recent, relevant and representative results of the progress made are discussed. A final subsection is added which summarizes the main findings of the section and the contribution of this research to previous work.

### *2.1. E-health internet of things*

IoT has become one of the most popular terms in recent years in the technology industry [3]. The IoT basically consists of embedding computing and communication capabilities into sensors and other *things* in the general environment. This evolution transforms these devices, making them smarter to fulfil their functions more effectively and perform other applications in order to improve the quality of life. There are numerous examples such as smart cities [4,5], sustainability [6], energy management, domotics and automation and other business models. The large increase in address space supplied by IPv6 is an important factor in the development of the IoT due to the greater ability it provides to address machines and connect them to the Internet.

The introduction of these new technologies in patient monitoring and diagnosis processes is increasingly important. In recent years we have seen a growing range of devices and sensors able to capture biomedical signals [7]. This includes specific-design sensors (a), new wearable devices (b) and even mobile smartphones (c).

(a) Sensors specifically designed for biological sensing, or biosensors, have led to a range of measurement techniques [8]. These elements not only provide measurement data, but are also appearing in analytical devices with signal processing capabilities to obtain advanced information on patients. They have traditionally been part of the medical equipment of hospitals and have been designed for use by medical staff.

(b) Wearable devices are a kind of electronic machine that interacts directly with the user [9]. These devices can be worn by people in the normal course of their activities, such as work, sport or resting. The first generation of wearables was basically used to alert the user (notifications of incoming emails, alerts, time, weather, etc.), but these devices are fast becoming a very popular technology. The acceptance of wearables by people has resulted in the creation of an industry of user-centric applications around these and the development of new features, especially biomedical sensing for health monitoring (respiration, electrocardiogram, oxygen blood saturation, skin temperature, etc.). Today, wearable health technology is also present in professional scenarios such as medical healthcare and professional sport.

(c) Mobile smartphones are mini portable computers held by users. These devices have a wide functionality and can run many applications, including, of course, talking on the phone. In addition, new smartphones have a lot of sensors of physical magnitudes such as the Global Positioning System (GPS), accelerometer, gravimeter and gyroscope which can be used to monitor human activity and peoples level of inactivity. Moreover, it is a fact that nowadays there are many *Apps* that can show the degree of physical activity in peoples lifestyles. For example, variables such as the speed of walking, running, climbing stairs and duration of physical activity can be measured by new healthy lifestyle Apps. The proliferation of smartphones and the high propagation rate of mobile devices connected among the population create a window of opportunity for the development of advanced health applications [10].

### *2.2. Collaborative processing*

Collaborative processing is the way in which the computing of tasks can be shared among several connected devices to achieve a common goal. Some applications are incapable of being processed by the devices used to interact with them.

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