

An Approach to Engineer and Realize Emergent Configurations in the Internet of Things

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ABSTRACT

The Internet of Things (IoT) is a fast propagating technology that is expected to emerge in almost all aspects of our daily life. The IoT environment is well known for being dynamic and uncertain. Connected devices, and their software, can be discovered at runtime and might also become suddenly unavailable. The involvement of the human in the loop complicates more the scene. People's activities are stochastic and their needs are not always predictable. Therefore, coping with the dynamic IoT environment should be considered as a first class requirement when engineering IoT systems. A useful concept for supporting this effort is Emergent Configurations (ECs). An EC consists of a dynamic set of devices that cooperate temporarily to achieve a user goal. This PhD work aims to use the concept of ECs as a basis for a novel approach for realizing IoT systems. More specifically, this thesis aims at: (i) producing characterization models for IoT systems and ECs; (ii) proposing a concrete architecture and an approach for realizing ECs.

CCS CONCEPTS

• **Software and its engineering** → **Software design engineering**; • **Computer systems organization** → *Other architectures*;

KEYWORDS

Internet of Things, Emergent Configurations, Software Architecture, Self-adaptation

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1 INTRODUCTION

The Internet of Things (IoT) is a widely spreading technology that has emerged in our daily life areas like transportation, surveillance and health-care to mention a few [6]. The IoT environment is dynamic and can change erratically. Connected devices are often

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resource-constrained and mobile. Thus, devices can join or leave IoT systems at anytime. The involvement of the human in the loop makes the situation more complex. Human activities are inherently situated and their goals can evolve unpredictably at runtime. Consequently, IoT systems should be able to respond to dynamic changes even when operating in uncertain environments [8].

Several architectures and approaches have been proposed to realize IoT systems. Although they share the same purpose, they do not share a unique definition and characterization of IoT systems [6]. The IoT-A project proposed a service based reference model architecture for the IoT [1]. The SIA is a service oriented architecture designed to enables IT systems to interact with IoT devices [7]. In SIA, services are composed at design time. Thus, automatic adaptations in response to unforeseen changes in the environment are not supported. Mayer et al. [9] proposed a service-oriented approach that aims to dynamically compose IoT mashups to achieve user goals. IoT things are abstracted into semantically described services. Goals are also represented in a machine understandable way. A plan which comprises a set of chained services is generated at runtime to achieve a goal. The approach is adaptable apropos the dynamic availability of services and the system itself. However, it seems to support only reactive adaptations and it does not represent all intrinsic dimensions of IoT systems (e.g., energy).

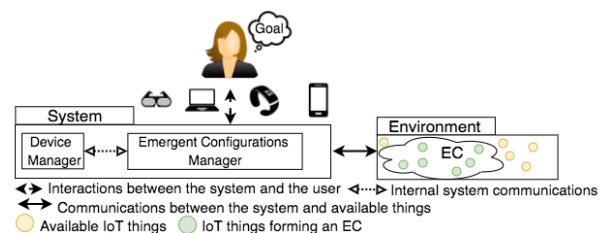


Figure 1: The ECs concept (based on [2])

To overcome the shortcomings of existing approaches, while answering the needs of IoT systems, this PhD thesis uses the concept of ECs, illustrated in Figure 1, as the basis of a novel approach to realize IoT systems [2, 5]. The term EC is defined as a set of things that connect and cooperate temporarily to achieve a goal. A thing is any (smart) connected object or device with its functionalities and services or applications [2, 5]. An example of an EC is about a user who expresses her goal to deliver a presentation in an unknown smart meeting room [2]. The room is equipped with several things e.g., temperature and light sensors, curtains actuators, a smart

projector and a smart screen. The goal is interpreted and a set of suitable things form an EC that satisfies the goal. For instance, the smartphone streams the presentation to the projector while curtains are closed automatically due to high light levels detected by the light sensor. During the presentation, the projector turns off suddenly. The user is automatically proposed to continue the presentation using the available smart screen.

The remainder of this paper is organized as follows. Section 2 describes the problem statement which this PhD thesis aims to address and the research method proposed to address the problem. Section 3 states the expected contributions of this thesis, reports about the current progress and presents the planned timeline for completion.

2 PROBLEM STATEMENT AND RESEARCH METHOD

The definition of ECs emphasizes the dynamicity aspects (e.g., run-time user interactions and temporary collaboration of things) as core aspects of the ECs vision. Coping with the dynamic IoT environment is considered as a first class requirement to engineer ECs. Thus, the hypothesis of this thesis is that ECs have the potential to be the basis of an effective approach for realizing IoT systems. Mainly, the thesis addresses the following research questions:

RQ1. *What are the characteristics needed to describe ECs?*

There is a lack of common understanding about the definition and characteristics of IoT systems [6]. To engineer ECs properly, a coherent characterization of IoT systems is required. To the best of my knowledge, there is no effort that comprehensively characterizes IoT systems.

RQ2. *What is a suitable software architecture to realize responsive and robust ECs?*

To realize ECs, the system architecture should be designed to ensure ECs *responsiveness* (with respect to dynamic interactions) and *robustness* (with respect to uncertainties). To the best of my knowledge, none of existing IoT architectures can fully meet the ECs requirements [2].

RQ3. *How can ECs realizing users' goals be formed and adapted automatically?*

Realizing ECs requires addressing several challenges e.g., how to analyze abstract user goals and how to form and adapt ECs based on surrounding environments. Other complex situations should also be addressed e.g., when users have competing goals.

The following assumptions are considered while addressing the aforementioned research questions: (1) ECs goals are achieved within well-defined spatial boundaries which contain their constituents (e.g., room, building) [2]. Consequently, the number of an EC constituents is not expected to be massive. This significantly mitigates the well known scalability issue in the IoT [6]; (2) ECs are realized to achieve user goals within non-critical time constrains; (3) things are automatically discovered and their functionalities are exposed following uniform standards.

To address RQ1, a **systematic literature review** will be conducted to develop characterization models for IoT systems and ECs based on existing taxonomies. The resulting models will be **evaluated** by assessing their competence to characterize a number of diverse IoT systems. Additionally, expert practitioners will be

involved in validating their correctness and comprehensiveness. The **design science research** method will be applied to address RQ2 and RQ3 in an iterative manner. The architecture and the approach will be **evaluated** for: (1) correctness: a prototype will be developed to realize an EC to achieve a user goal by exploiting e.g., formal methods; (2) scalability: simulations will be performed with an increasing number of ECs constituents; (3) additional criteria will be specified at later stages.

3 RESULTS AND FUTURE WORK

This PhD thesis **aims to contribute** to the body of knowledge by providing: (1) characterization models for IoT systems and ECs through taxonomies; (2) a concrete architecture and an approach for realizing ECs. During the **first year** of the PhD studies, we have proposed an architectural style for realizing ECs [2]. In addition, we conducted a preliminary study on how to engage (part of) available things in agreements to form and/or adapt ECs [4]. Moreover, we illustrated how ECs can be regarded as Systems and Systems of Systems [3]. During the **second year**, ongoing work includes the characterization models, the approach and the architecture for realizing ECs by refining a subset of the ECs architectural style components. During the **third year**, it is planned to extend the approach and architecture by refining the rest of the architectural style components. More prototypes, realizing different cases, will be developed to validate the proposed architecture and approach during the **fourth year**. During the **fifth year**, it is planned to work on the PhD thesis which will be defended by June 2021.

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