Microservices: A Mapping Study for Internet of Things Solutions

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***Abstract*—The Internet of Things (IoT) involves the connectivity of a number of different physical and virtual devices, allowing the development of new services and applications. These intelligent objects, along with their tasks, constitute domain-specific applications (vertical markets), while ubiquitous and analytical services form domain-independent services (horizontal markets). The development of these applications and services in these markets brings challenges such as deployment, scalability, integration, interoperability, mobility and performance. Recent researches indicates that Microservices have been adopted in several domains such as IoT. This paper provides an overview of the current state of the art (studies selected by May 2018) regarding the adoption of Microservices in the development of IoT applications by means of the mapping study methodology. In this context, we present the eighteen selected studies, the existing contributions and the future research perspectives.**

***Index Terms*—Microservices, Reactive Microservices, Internet of Things; Cloud Computing, Fog Computing, systematic mapping study**

I. INTRODUCTION

Nowadays, a few applications are using the Microservices architecture in domains such as IoT and Mobile [1], in order to support the construction of large-scale systems that are more robust, resilient, elastic and better adapted to meet current IoT applications demands. Microservices aim to build, manage and design architectures of small autonomous units [2]. The applications based on the Microservices architecture are polyglot, that is, they are constructed from the programming language of the choice of the developer and the deployments are carried out continuously [3], a few dozen times a day [4] and hundreds of times in some cases [5], making the use of applications by the numerous users more dynamic.

In IoT, Gartner [6] expects about 21 billion devices by 2020. These new devices will be able to interact by providing new services in different domains and environments, generating added value for the user. According to Al-Fuqaha et al. [7], and Shahid and Aneja [8], there are diverse domains that constitute vertical markets (e.g. smart cities, smart houses, healthcare) and horizontal markets (e.g. ubiquitous computing and analytical services), which form domain-independent services.

From these markets, there is a set of intelligent applications that can be built in different scenarios and that have an impact on the people's daily routine [8]: In **Prediction of natural disasters**, the combination of sensors can help the prevention of natural disasters and taking appropriate action in advance. Regarding **Industry applications**, intelligent applications can assist in the management of a fleet of cars for an organization. **Intelligent transport system design** can help the application of traffic laws, the reduction of environmental pollution, anti-theft systems, the prevention of bottlenecks, among others. In **Agriculture application**, an intelligent system will help agronomists gain a better understanding of plant growth models and also adopt best agricultural practices. In **Design of smart cities**, IoT can help design smart cities, for example, in monitoring air quality, efficient street lighting, among other scenarios.

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Considering the importance of analyzing the adoption of Microservices in the development of IoT applications, a study that provides a broad view of recent publications and contributions in this area would be of great importance. For this purpose, we carried out a systematic mapping study to identify and interpret the publications available in the Microservices and IoT research field.

The remainder of this paper is organized as follows. Section II describes background information of the topic. The design of the study is presented in Section III. The results of the mapping study are discussed in Section V. The related works are discussed in Section IV, while the conclusions are presented in Section VI.

II. BACKGROUND

A. SOA for IoT

In the last years researchers have presented solutions for the development of IoT applications from the perspective of the SOA architectural style. Eliasson et al. [9], López and García [10], Zhang et al. [11] are part of the research that has been applied in different projects, aiming to provide scalability, portability and reusability. However, according to Cerny et al. [12] and Newman [13], SOA applications present some limitations: Deployment, Scalability, Performance, Management and Interoperability.

B. Microservices for IoT

To address these limitations when developing IoT applications, researchers are recently adopting Microservices. According to Fowler and Lewis [2], Microservices is a model for implementing an application as a set of small services, each running in its own process and communicating with lightweight mechanisms, often as an HTTP resource API. In contrast to traditional architectures for designing applications in IoT, the Microservices architecture offers advantages such as those discussed by Newman [13]: Technology Heterogeneity; Resilience; Scalability; Ease of Deployment; Organizational Alignment which will enable the development of large-scale IoT applications.

III. RESEARCH METHOD

In this study, we performed a systematic mapping study based on Petersen [14] and Kitchenham [15] to identify studies on the adoption of Microservices published by the scientific community, to address the inherent challenges of the IoT architecture application layer.

1) Research Questions: In order to formulate the research questions we used three points of view: Population, Intervention and Outcomes as defined by Kitchenham [16]. From these points of view and with the objective of identifying the relevant studies in the research area of Microservices in the context of IoT, we formulated the following questions:

- **RQ1** - What are the studies published by the scientific community on the adoption of Microservices in the development of IoT applications?
- **RQ2** - What are the main contributions of the identified studies?
- **RQ3** - What are the perspectives and trends of research in the area of Microservices in the context of IoT?

2) Search Strategy: The terms ”microservices for internet of things”,”benefits microservices for internet of things”,”reactive microservice”, ”microservice”, key benefits of microservices for internet of things”, ”Practical Microservices”,”design microservices”, ”distributed services” and “microservices architecture” were researched in articles published in books, journals, conferences and workshops. The research was restricted to articles published between 2014 and 2018.

3) Source: Based on Kitchenham [16] and Petersen [14], we identified the most complete scientific databases in computer science:

- ACM Digital Library
- IEEE Xplore Digital Library
- SCOPUS
- Science Direct
- Springer

The process of selecting the publications in these databases involved the following steps:

- Initial search: In this step, we searched the databases. The use of the terms in the selected databases resulted in a number of publications: ACM Digital Library (29), IEEE Xplore Digital Library (97), SCOPUS (191), Science Direct (68), Springer (9).
- Impurity removal: In this step, we removed items that were not research documents from the search results, aiming to have a coherent set of potentially relevant research studies.
- Merging and duplicates removal: In this step, we established a single set of data regarding the publications found. Additionally, duplicate entries were removed.
- Application of selection criteria: In this step, the articles were checked concerning relevance, in relation to the research questions related to this systematic mapping study. The titles, abstracts and keywords were scanned to determine the relevance of the articles and whether they should be included (I) or excluded (E) for the purposes of this study, based on the criteria listed below:
- **I1** - Studies on Microservices in the Internet of Things in the phases of the software life cycle
- **I2** - Studies on the architectural properties of Microservices to deal with implantation, testing, resilience and elasticity in the Internet of Things
- **I3** - Studies which compared SOA in IoT with Microservices in IoT
- **E1** - Studies on Microservices with insufficient information
- **E2** - Studies that did not have Microservices as their main topic of research or analysis
- Snowballing: refers to using the reference list of a paper or the citations to the paper to identify additional papers.

4) Categorization and Classification schemes and processes: In this step, we performed a qualitative evaluation of the selected papers and classified them based on the criteria (e.g. Evaluation Research, Opinion Paper, Solution Proposal, Experience Paper, Validation Research and Philosophical Paper) defined by Roel et al. [17].

5) Data extraction: In the last step, the data of the selected publications were extracted to answer the research questions related to this work.

IV. RELATED WORKS

A few secondary studies are currently being developed in order to obtain an overview of the adoption of Microservices, especially in Cloud Computing. The work of Di Francesco, Malavolta and Lago [1], Alshuqayran et al. [18] and Pahl et al. [19] focus on systematically comparing the existing research in Microservices, and their application in the cloud.

In a more recent work, Campeanu [20] carried out a systematic mapping study similar to the one developed in this paper; however, the works differ in relation to the research questions and to the focus of our research that allowed different results to be obtained.

V. RESULTS

A. *RQ1*

The academic interest in Microservices for IoT application development is recent, as can be viewed through the year of publication of several works presented in Table I.

Table I
PUBLICATION SELECTED.

ID	Paper Name	Paper Format	Year
P1	Architecture of an interoperable IoT platform based on microservices [21]	Conference	2016
P2	Microservices approach for the internet of things [22]	Conference	2016
P3	Designing a Smart City Internet of Things Platform with Microservice Architecture [23]	Conference	2015
P4	SeCoS: Web of Things platform based on a microservices architecture and support of timeawareness [24]	Journal	2016
P5	Location and Context-Based Microservices for Mobile and Internet of Things Workloads [25]	Conference	2015
P6	Microservice-based IoT for smart buildings [26]	Conference	2017
P7	Microservices as Agents in IoT Systems [27]	Conference	2017
P8	Role Modeling of IoT services in industry domains [28]	Conference	2017
P9	Exploiting interoperable microservices in web objects enabled Internet of Things [29]	Conference	2017
P10	A Secure Microservice Framework for IoT [30]	Conference	2017
P11	Distribution of microservices for hardware interoperability in the Smart Grid [31]	Thesis	2015
P12	An Open IoT Framework Based on Microservices Architecture [32]	Journal	2017
P13	NIMBLE collaborative platform: Microservice architectural approach to federated IoT [33]	Conference	2017
P14	A Microservice Architecture for the Intranet of Things and Energy in Smart Buildings: Research Paper [34]	Conference	2016
P15	Microservices model in WoO based IoT platform for depressive disorder assistance [35]	Conference	2017
P16	Investigating Performance Metrics for Scaling Microservices in CloudIoT-Environments [36]	Conference	2018
P17	A Reactive Microservice Architectural Model with Asynchronous Programming and Observable... [37]	Thesis	2017
P18	Towards Osmotic Computing: Analyzing Overlay Network ... [38]	Conference	2018

Table II
RESEARCH CONTRIBUTIONS.

Classification	Paper	Contribution	Problems	Domain
Evaluation research	P2 P1O P14 P16 P17 P18	Patterns and best practices Architecture Middleware Performance metrics Methodology Performance	Self-Containment, Monitoring, Orchestration, Versioning Secure reuse, deployment, development Scaling Development of IoT middleware Connectivity and Network Overlays	Agnostic Smart building CloudIoT Agnostic Cloud, Edge and Fog Computing
Solution Proposal	P1 P4 P5 P6 P7 P9 P12 P13 P15	Middleware Plataform Context-based applications Prototype platform Management Service Architecture Framework Architecture Architecture	scalability/interoperability scalability/maintenance development scalability Collaboration of distributed modules Interoperability Heterogenety/Scalability/Discovery scalability/integration Interoperability	Agnostic Web of Things Agnostic Smart Building CloudIoT Web of objects Agnostic Industry 4.0 Web of Objects
Validation research	P11	Middleware	Heterogeneity	Smart Grid
Experience Report	P3	Plataform	Data management	Smart City
Philosophical papers	P8	Service Modeling	Modeling	Industry

B. *RQ2*

Considering the phases of the software lifecycle, the works presented in Table I show that when architecting Microservices for IoT, Design is the predominant phase, and with data solutions applied in Cloud Computing and Fog Computing. With gradual maturity, there is a need for works that investigate complexities in the other phases (i.e, implementation, maintenance, evaluation and operation). Table II shows the contributions and problems of each selected study.

C. *RQ3*

Microservices are a recent concept and they have been successfully adopted by companies such as Netflix and SoundCloud in their solutions in Cloud Computing. In IoT, the adoption of Microservices is still little, but with the gradual maturity of studies, other fields of research associated with Microservices will be explored, such as: Machine Learning, Containers, Reactive Systems, FOG Computing, Continuous Integration and Deployment, and formal methods for specification of Microservices.

VI. FINAL REMARKS

The aim of this work is to provide a broader research on the adoption of Microservices in IoT applications. Specifically, we carried out a systematic mapping study in 18 primary studies and produced an overview of the state of the art in the Microservice architecture and its application in IoT. The results of this study will benefit researchers willing to contribute to the field. Future work includes carrying out a systematic review which aims to identify how the architectural properties of Microservices can be applied to address the inherent challenges of the application and middleware layers of the IoT architecture.

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