A Mapping Study on Microservice Architectures of Internet of Things and Cloud Computing Solutions

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Abstract— **Internet of Things is a fairly new paradigm adopted by the industry, which offers the connectivity, via wireless systems, of all the devices that surround us. One of the challenges of IoT relates to the required resources to store and compute the huge amount of data resulted from devices' connections. Cloud computing is a solution to the IoT challenges; it provides on-demand resources in an easy-to-access manner. Another trend in the enterprise world is the usage of microservice architectures. Being a newly developed paradigm, and although its principles are defined, it is difficult to have a vision of the existing microservice-based research solutions. This paper, through the mapping study methodology, provides an overview of the current state-of-the-art and -practice regarding the usage of microservice architectures by IoT and cloud computing solutions. More specifically, we synthesize the data from 364 selected studies and describe the research types, number of publications and their main venues**.

Keywords - Internet of Things; microservice; cloud computing; IoT; SLR; systematic mapping study.

I. INTRODUCTION

The Internet of Things (IoT) [4] is a modern paradigm that has the purpose to connect all the objects that surround us. One of its effects is the huge amount of data that is generated. A challenge that comes with IoT is the need to stored and process, in an easy interpretable form, the amount of data resulted from the devices' connections. Cloud computing [6] is a feasible solution that complements IoT via features such as storage, processing power, analytics instruments and monitoring solutions, tackling in this way some of the IoT challenges.

Another trend in the development of software is the microservice architecture (MSA). MSA is a recent developed software architecture pattern, which is already adopted by various companies, such as Amazon, eBay and Netflix. It promotes the development of applications through the composition of small and independent services referred as *microservices*. Each such (micro)service belongs to an independent process. The service communication is realized through lightweight mechanisms such as the HTTP resource API [5].

In the context of cloud computing and IoT, the software is built using a series of services, and delivered to the end-users through the Internet. There is a strong connection between microservice architectures and cloud applications. For example, microservices are identified as containers, i.e., lightweight mechanisms utilized at the Platform-as-a-Service layer, to package, distribute and orchestrate applications [7]. However, there exist different obstacles when employing microservice architectures for IoT and cloud computing services. In this paper, we are interested in the state-of-the-art and -practice publications that facilitate the development of microservice applications for IoT and cloud computing.

The main contributions of this paper are: *i)* a reusable framework to describe the trends specific to microservice architectures of IoT and cloud computing solutions, and *ii)* an up-to-date mapping of the state-of-the-art and -practice research in the context of the studied area. The audience targeted by this study is composed of: *i)* researchers that are interested in contributing in the development of the aimed research area, and *ii)* practitioners that desire to understand the existing targeted research area, in order to adopt the existing solutions in industry.

The remaining of this work is structured as following. 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 IV. The related works are discussed in Section V, while the conclusions and future work directions are presented in Section VI.

II. BACKGROUND

This section presents background information on microservices, Internet of Things and cloud computing solutions, as follows.

A. Microservices

Microservices, a new approach used in software architecture, promotes the development of applications by composing small and independent services. Each service is independent and the (inter-service) communication is realized through lightweight mechanisms such as HTTP API [5]. Common characteristics of the microservices are the automated and independent deployment process, and a decentralized control of the languages. Opposite to the monolithic style, microservices can be written in different programming languages or use different data models.

Opposite to the microservice paradigm, there are advantages but also disadvantages when using the traditional monolithic approach. A monolithic application is easier to develop (unless it is big and complex) and easier to deploy. On the other side, understanding and modifying monolithic applications are few of its disadvantages. Moreover, it is more difficult for the developer to work in an independent manner. Another shortcoming is that the technology used is difficult (to almost impossible) to change.

Although adopting microservices architectures introduce many benefits, there are also challenges that are discussed in the following paragraphs. Creating an application using the microservice approach is similar with creating a distributed system, i.e. , the complexity is increased. Furthermore, similarly with testing distributed systems, testing microservice-based applications is more difficult than monolithic-type of applications.

One of the most difficult challenges is to decide the microservices of an application. There are some approaches[1] that can provide assistance, such as:

- identify services corresponding to the utilized business capabilities,
- identify services that have the responsibility to execute particular actions,
- identify services responsible for all operations of the type resources.

B. IoT and cloud computing

A novel paradigm that is gaining recognition in the context of wireless systems is the Internet of Things. The core idea of this paradigm is to use all the devices that surround us, e.g., Radio-Frequency IDentification tags, sensors, mobile phones, in order to cooperate to reach common goals [3]. Connecting multiple devices leads to a huge amount of information; this information needs storage, and to be efficiently processed. Moreover, the results of the processed data need to be delivered in an interpretable form in order for the regular end-users to easily understand. Other challenges of the IoT are related to the interoperability of the connected devices, while guaranteeing the privacy and security of the data.

A solution to the challenges regarding the storage and computation power that the IoT data requires, is the cloud computing. Cloud computing is another novel paradigm that provides on-demand access to a pool of computing resources [6]. The access to the cloud computing should be characterized by a minimal effort. Besides the access to computing resources, cloud computing provides also the applications to access the resources. The end-users connection to these applications (referred as Software-as-a-Service) is done through Internet. Among the benefits of cloud computing we mention the on-demand self-service, elasticity and resource pooling.

1 http://microservices.io/patterns/microservices.html

III. STUDY DESIGN

A systematic mapping study has the purpose to provide, thorough identified published works, a high-level overview over a particular research area. Following the well-established guidelines to design systematic mapping studies [9], the following paragraphs present the design of our study.

A. Research questions

The research questions are the means to get answers about specifics of in-questioned domain. Focusing on the research area of microservices in the context of IoT and cloud computing, we developed the following questions:

RQ1: How many publications per year are found in the research area?

RQ2: Which are the main venues for the publications of the research area?

RQ3: Which are the main publication types in the research area?

B. The search string

The second step is to define the search string used in searching for existing published article. Our defined string is the following:

*("internet of things" OR *iot OR "cloud computing" OR "cloud based") AND (microservice* OR micro-service* OR "micro service"*)*

The Boolean operators AND and OR are used to unite the keywords in the search string. Moreover, we use a wildcard to not miss relevant publications. For example, when using the combination **iot*, it may result the *iiot* keyword, which is the abbreviation for the *industrial Internet of Things*.

C. Sources

After defining the search string, the next step is to establish the sources of publications. We identified the four most largest and complete sources as:

- IEEE Xplore Digital Library[2],
- ACM Digital Library[3],
- Scopus[4], and
- Web of Science[5].

After the databases are identified, we searched publications using the defined search string.

The selection process of the publications considered in this work is described using the following steps:

2 http://ieeexplore.ieee.org

3 https://dl.acm.org

4 http://www.scopus.com

5 http://webofknowledge.com

Step 1. Initial search. Searching the defined search string in the established sources resulted with a number of 138 publications for IEEE Explorer, 137 publications for ACM Library, 212 publications for SCOPUS, and 93 publications for Web of Science, as illustrated by Figure 1. The total number of considered publications is 580. For consistency reasons, the search string was applied to title, abstract and keywords in all four used libraries.

Step 2. Merging and duplicate removal. In this step, we merge the resulted publications from both of the databases, in a single dataset. Moreover, the duplicated entries are removed. The removed entries are matched by the title, authors, year, and publication venue fields. In this step, it resulted a total of 407 publications.

Step 3. **Application of selection criteria**. After removing the duplicated entries (step 2), we further filter the merged dataset according to a set of inclusion and exclusion criteria. Our defined inclusion (I) and exclusion (E) criteria are presented as follows:

I1. Publications focused on microservice architectures of IoT or cloud computing solutions.

I2. Publications that are peer-reviewed, i.e., journal, conference and workshop articles.

I3. Publications that are written in English.

E1. Publications that are tutorial papers, editorials, abstracts and extended abstracts, and proceeding papers.

E2. Publications that are not available as full-text.

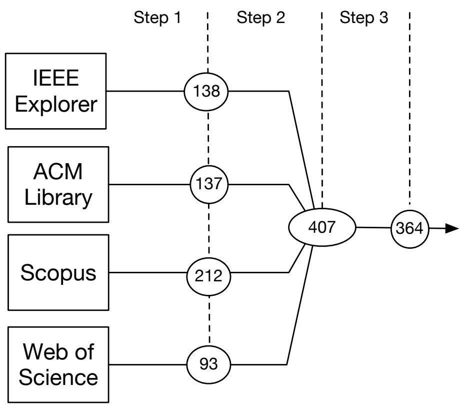

Figure 1. Number of publications

After applying the inclusion and exclusion criteria, the set ended up with a total of 364 publications, as illustrated in Figure 1.

D. Data extraction

In the last step, the data from the selected publications is mapped to the three categories corresponding to the research questions. The first category contains information about number of the publications distributed over the years. The second category extracts the venue information where the selected entries were published. The third category presents the main topics addressed by the publications from the selected set. These categories are described in more details in the following section.

IV. RESULTS

A. Publication distribution (RQ1)

The distribution of publications over the years is presented in Figure 2. We notice that the first papers (i.e., 33 publications) were published in 2015, that is, one year after the microservice paradigm was consistently used [8]. In 2016, the number of publications grows significantly (i.e., 123 publications), while in 2017 is even higher, reaching to a total number of 197 publications. In 2018, there are only 11 publications. We mention that this study was conducted in January 2018, which explains the low number of publications from 2018.

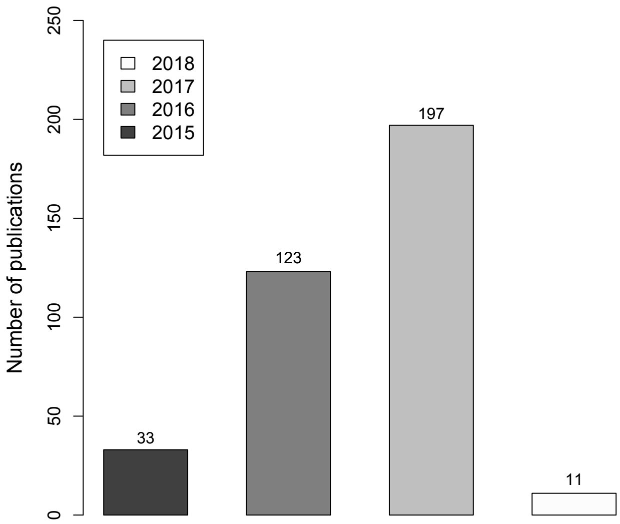

Figure 2. The distribution of the publications over the years

The publication distribution clearly describes the scientific interest on microservice architectures in the context of IoT and cloud computing solutions. We believe that the number of publications for 2018 will be significantly higher than the articles published in 2017.

B. Publication venues (RQ2)

The main five publication venues for the considered research area are displayed in Table I. We observe a large variety of publication venues for the considered 364 publications, where the Symposium on Service-Oriented System Engineering (SOSE) is the venue with the most publications. It is closely followed by The International Conference on Cloud Computing (CLOUD) and International Symposium on Cluster, Cloud and Grid Computing (CGRID). The large variety of venues is an indication that the microservices and/or IoT and cloud computing are orthogonal research topic with many other concerns.

TABLE I. THE MOST USED VENUES IN THE RESEARCH AREA

Rank	**Publication type**	***Acronym of the Publication Venue***	***Number of publications***
1	conference	SOSE	15
2	conference	CLOUD	11
3	conference	CCGRID	10
4	conference	UCC	10
5	conference	CloudCom	8

C. Publication types (RQ3)

From the total of 364 publications considered in this study, 349 were published in conferences while the rest (i.e., 15) were published in journals. The huge amount of conference publications, alongside with the answer from RQ1, clearly indicate that the research topic is maturing as a research subject, despite being a relative newly developed topic.

V. RELATED WORK

Being a relative newly developed paradigm, microservices are studied by only few studies, as follows. The most relevant work is the mapping study of Pahl et al. [8]. The authors identify, taxonomically classify and compare the research publications on microservices and their usage in the cloud. The results of the mapping study are based on 21 selected studies. We point out that this study was published in January 2016. The results of our mapping study are much more conclusive regarding the increased attention of the microservices in the cloud computing and IoT. Furthermore, we use a more extended search string compared to the one used by Pahl.

There are other mapping studies on microservices. We mention the one developed by Alshuqayran et al., which study the challenges, architectural diagrams and the quality requirements of microservices [1]. Dragoni et al., via their mapping study, provide a description of the past and current microservice characteristics [2]. The authors also introduce their viewpoint on the future of the microservices. Our mapping study can be seen as a complementary to these studies, by addressing a narrower topic of microservice research area.

VI. CONCLUSIONS

The microservice architecture, a relatively newly developed paradigm, receives great attention from the enterprise world. Companies such as Netflix, eBay and Amazon successfully adopted this paradigm in their business model. Moreover, offering development advantages such as independent deployability and lightweight mechanisms, the microservice architecture is a feasible solution for IoT and cloud computing.

Because the maturity of the research work regarding the adoption of microservice architectures by IoT and cloud computing is quite low, we cannot draw strong conclusions. However, based on the existing state-of-the-practice research, pointers about the direction of this area may be derived.

As a conclusion, our mapping study shows an increased interest in this research area. The number of publications in 2016 is four times larger than to the previous year. Moreover, the number of publications that exist in 2017 is higher (i.e., 62%) that the previous year. The study captured only few published articles (i.e., 11) for 2018 due to the time when this study was developed (i.e., January 2018).

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