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SLAs for Industrial IoT: Mind the Gap

[Position Paper]

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***Abstract*—Cloud computing and Internet of Things (IoT) are computing technologies that provide services to consumers and businesses, allowing organizations to become more agile and flexible. The potential business values that cloud consumers can achieve depend a lot on the quality of service in the provided cloud services. Therefore, ensuring the quality of service through service-level agreements (SLA) for such cloud-based services is crucial for both the service providers and service consumers. As SLA is critical for cloud deployments and wider adoption of cloud services, the management of SLA in cloud and IoT has thus become an important and essential issue. In this paper we provide an understanding of the current status and maturity level of SLA management in industrial IoT and academic efforts in this field. We also conduct a preliminary survey of current research on SLA management in order to identify open challenges and gaps that need to be addressed in future research directions. In particular, we investigate how to provide useful SLA management support adapted to the maturity level and current industrial practices, and shorten the gap between academia and industry.**

I. Introduction

Cloud Computing has emerged as a new paradigm in the field of network-based services within many industrial and application domains [1]. It offers a pool of virtualized computing resources at various levels, covering infrastructure, platforms or software delivered to users as on-demand services from the cloud. In this way, cloud computing is changing the services consumption and delivery platform as well as the way businesses and users interact with IT resources.

The Internet of Things (IoT) extends the cloud computing concept beyond computing and communication to include not only computational resources but also the physical devices [2], [3]. Industrial IoT uses sensors, machine-to-machine collaboration and various technologies to gather and analyze data from the physical and virtual world for optimized operations and providing services. Accordingly, cloud computing and IoT are computing technologies that can provide services to consumers and businesses, allowing organizations to become more agile and flexible in pursuing new revenue streams and new business models.

During the past decade, the IoT has gained significant attention both in academia and industry. According to a recent study by Gartner [4], the current count of IoT devices is around 6.4 billion devices (not including smartphones, tablets, and computers), and it is expected to grow up to 21 billion by 2020. The advent of IoT technologies poses a number of challenges to the industrial and research communities [5], [6], [7]. For example, building new services in the cloud or designing cloud-based IoT solutions into existing business contexts is a complex engineering process, involving many factors and concerns [8], [9], [10], including security issues [11], [12] and integration issues [13], as well as development and formal analysis issues [14], [15]. One of the most relevant aspect is the *reduced operational governance control*, i.e., a cloud consumer has less control of the actual service level being offered by the cloud provider, compared to on-premise services. In particular, from the industrial perspective, the availability of suitable contracts and performance guarantees, and thus of Service Level Agreements (SLAs) plays a major role in the acceptance and adoption of IoT devices in an industrial context.

While there has been a lot of work on IoT, cloud computing and their application in industrial systems, e.g. [16], [17], [18], [19], [20], not much attention has been paid on modeling resource requirements and developing SLAs. In this paper we investigate the reasons for such a gap, highlighting what are the main differences between the industrial and academic perspectives. The aim of this paper is to highlight the main limitations of industrial IoT solutions in terms of provided SLAs by the academic efforts in the field.

The rest of the paper is organized as follows. Section II analyzes the state-of-practice for SLA management for industrial IoT. Section III presents the preliminary analysis of the current research efforts in SLA. Section IV concludes the paper and recommends for future work.

II. SLAs in industrial IoT

Industrial IoT and cloud infrastructures are enabling technologies for next-generation smart industries, typically referred to as Industrie 4.0 [21], [6]. In such a vision, machines are connected as a collaborative community, and are able to self-adapt, self-organize, and self-optimize thanks to the use of advanced technologies in self-adaptive systems [22], [23], [24], collaborative robotics [25], as well as cloud and IoT technologies [26].

When resorting to third-parties cloud IoT services, the fundamental limitation becomes the performance that the service consumer experiences in the actual application. Many industrial IoT applications are, in fact, time- and safety-critical, such as human-robot interaction [27], [28], autonomous vehicles [29], and many more [30], and in general involve rapid

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real-time sensing of unpredictable conditions and instantaneous responses. For example, autonomous vehicles should be able to detect imminent collisions and take evasive actions. It is therefore clear that assurances for industrial IoT through the definition of suitable SLAs are of utter importance.

A good SLA: According to Wustenhoff [31], a good SLA helps the service provider to promise what is possible to deliver, and deliver what is promised. A bit more precise definition is provided by Sturm et al. [32], who define specific characteristics that a good SLA should have:

- **Attainable**, it is possible to meet the promised level of service (analogously to [31]);
- **Meaningful**, the SLA must be relevant to all the parties to the agreement;
- **Measurable**, it should be possible to measure the actual level of the service, and compare it with the agreement;
- **Controllable**, the service provider must have the ability to exercise control over the factors that determine the level of delivered service;
- **Understandable**, the SLA should be related to concepts and quantities that can be understood by both parties, i.e., they should be readily related to the user experience;
- **Affordable**, providing the SLA should be cost-effective, and it should not impact other provided services.
- **Mutually acceptable**, the definition of the SLA should be the result of the negotiation between the service provider, and the service consumer, and "It is not possible for a viable, effective agreement to be arrived at if one of the parties to the agreement simply dictates the terms of the agreement." [32, Ch. 4].

Current status of SLAs in industry: According to Berthelsen [33], SLAs have been a low priority in the machine-to-machine and IoT partly due to the technical and partnering complexity of many solutions.

Having these characteristics in mind, we briefly analyzed what are the SLAs provided by some of the major players in industrial IoT. Analyzing, for example, the Microsoft IoT Hub [34] technology, they "promise that at least 99.9% of the time deployed IoT hubs will be able to send messages to and receive messages from registered devices and the service will be able to perform create, read, update, and delete operations on IoT hubs."[1]. Notice that for the "Automation Service", they guarantee that "at least 99.9% of runbook jobs will start within 30 minutes of their planned start times" [35]. Analogously, other leading companies, such as Amazon, Cisco, IBM, or Intel, seem to provide guarantees only on uptime, with little or no guarantees on timing requirements, or other relevant aspects for industrial IoT. This is further confirmed by the study [36], which also observes a lack of consistent way of drafting SLA with respect to SLA attributes descriptions, e.g., availability/uptime/downtime calculations vary from different public providers.

In order to better understand the current state-of-practice of SLAs in industrial IoT, we have conducted interviews with some of our industrial collaborators that are currently developing IoT solutions. The interviews have confirmed the presented trend.

[1]No SLA is provided for the free version.

III. The academic perspective

What is currently needed?: SLAs in industrial IoT seem to be at a very early stage, and different relevant improvements have been highlighted in the literature.

Myerson [37] points out the importance of **standardizing** SLAs in cloud computing, and even in this context we are far from achieving it. When it comes to extending cloud computing with IoT, this becomes even more difficult, since the service provided by one will depend on the service provided by the other. Providing templates for the definition and negotiation of SLAs would enable a better development and management from both the provider and the consumer perspectives [38]. This would also ease the life-cycle management of SLAs.

Buyya and Dastjerdi [39], as well as Papadopoulos [7] highlight the need of **probabilistic guarantees** in the definition of SLAs for cloud computing. A better and more precise specification of the SLAs is in fact essential for the development of other services in an industrial context.

Moreover, the huge uncertainty present in the cloud calls also for **benchmarking** methodologies, and frameworks [40], [41], [42], that are currently not well-established, and mostly under development. Also, uncertainty introduced by the cloud has to be accounted for when dealing with benchmarking [43], in order to provide sensible results to be used in the definition of SLAs.

Academic trends: In order to better understand the academic approach to the problem we conducted a preliminary analysis of the current trends in the field. In particular, we selected three different databases, i.e., the IEEE Xplore digital library[2], Web of Science[3], and Scopus[4], and we conducted a search in the three databases with the string "*("service level agreement" OR sla) AND (iiot OR "internet of things" OR cloud)*", selecting only results from 2012 to 2016 (last five full years). Note that the duplicate entries were removed.

Figure 1 shows the number of papers and books published on SLAs per year. Notice that among the obtained results there might be non-relevant papers, but we assumed that they are just affecting the absolute number and not the overall trend. It is possible to see that there is an increasing interest in the scientific community on the matter. The lower value for 2016 can be explained considering that some of the papers that were accepted for publication in the last year might not be already available in the considered databases, or the proceedings of the conference might be not yet ready.

If we then separate the obtained entries by type of publication, as shown in Figure 2, we can see that there is a similar trend for the journal publications, while the conference publications present a similar drop for the year 2016, probably due to the aforementioned reasons.

Finally, we can also analyze how the publications are distributed among the different types. In particular, Figure 3

[2]http://ieeexplore.ieee.org/Xplore/home.jsp
[3]http://webofknowledge.com/
[4]https://www.scopus.com/

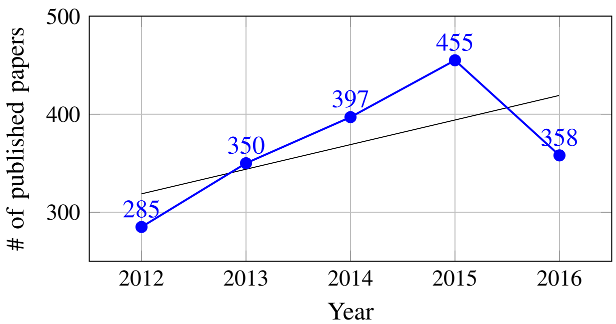

Fig. 1: Number of papers and books published on SLAs in IoT/industrial IoT in the last five years. The black line represents the linear trend of the obtained data.

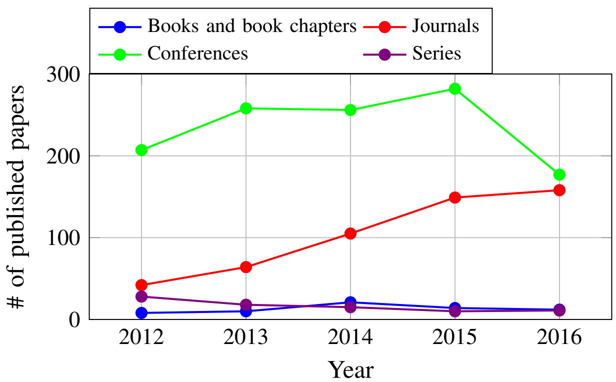

Fig. 2: Number of papers and books published on SLAs in IoT/industrial IoT in the last five years divided by type of publication.

shows a pie chart that highlights that the great majority of the publications were published in conference proceedings, which is in line with the general trend in computer science, while the number of books and book chapters is quite low. This can be justified by the fact that SLAs for IoT is rapidly evolving, and academics prefer a faster way to spread advances on the matter, rather than going for journal publications or even books.

Apparently, this analysis is still at a preliminary stage, but it allows us to highlight mainly two facts:

1) The interest of academics on the matter is increasing over time;
2) Academics are currently in a phase of exploration of the potential approaches for addressing the relevant problems in the field, and of the development of novel frameworks and techniques for helping the definition of the next-generation SLAs.

Among the obtained papers, we manage to identify the following macro-areas on which the scientific community focused their efforts:

1) **SLA modeling and definition**, i.e., templates, frameworks or languages that allow for a more agile management and definition of SLAs.

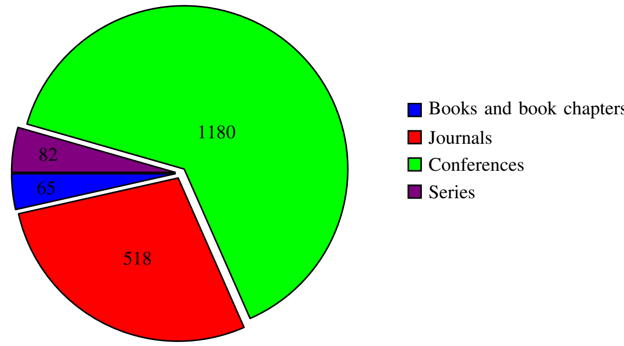

Fig. 3: Distribution of the type of scientific publications of the last five years.

2) **SLA negotiation**, i.e., how to manage discrepancy between what the provider promised in terms of SLAs, and what the consumer actually experiences.
3) **SLA monitoring and measurement**, i.e., how to actually measure the level of service and closely monitor to verify the provided service level with respect to the agreed service level.
4) **SLA enforcement, compliance or violation**, i.e., the definition of policies for the enforcement of the SLA both from the provider and the consumer perspective, as well as resource management techniques.
5) **SLA evolution**, i.e., how to manage the life cycle of an SLA.

All these aspects represent relevant faces of the same problem, but they do not find direct mapping to their industrial counterparts. In fact, at the current stage, the application of the ideas developed in the scientific community to industrial environments is pretty limited.

A deeper analysis to better understand what are the current trends in the scientific community is still needed and underway. This analysis would allow one to identify more mature aspects for the management of SLAs, and how a technology transfer could be possible to bridge the gap between the current industrial state-of-practice, and the scientific research.

IV. Conclusion and Future Work

While in the industrial state-of-practice, the definition and use of SLAs for IoT is mostly limited to uptime, the scientific research community has investigated a number of different aspects that have been highlighted. One of the main reasons that can justify such a gap is that the subject is still young, and the scientific community is developing frameworks, languages and techniques for the management of SLAs.

On the other hand, we envision that the current industrial panorama will change, since more and more applications will need to be supported by fit-for-purpose SLAs. Future factories will need a standardization of SLAs, with the possibility of autonomously and efficiently managing all the presented aspects, from the definition to the negotiation, from the monitoring to the enforcement of SLAs.

As a future work, we plan to conduct a systematic review [44] which will help in better identifying and opening challenges and gaps that need to be addressed in future research directions.

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