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# A Systematic Literature Study on Definition and Modeling of Service-Level Agreements for Cloud Services in IoT

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**ABSTRACT** The cloud computing paradigm provides remote computing resources to the cloud service consumers and businesses. When combined with Internet of Things (IoT), both technologies open up a wide range of new possibilities for more agile and flexible applications. However, guaranteed quality of service is essential in provisioning of cloud services, which makes Service Level Agreements (SLAs) a focal point in the cloud computing and IoT ecosystem. The SLA definition and modeling phase is crucial in establishing SLAs between service providers and consumers. This paper identifies that the research on definition and modeling of SLAs for cloud services in IoT is widely dispersed and there is a lack of a systematic and comprehensive literature review. Thus, in this paper we build on top of a previously conducted systematic mapping study on management of SLAs for cloud computing and IoT to perform a comprehensive systematic review and discuss sub-categorization of the definition and modeling aspects of SLAs for cloud services in IoT. Furthermore we analyze the extracted relevant literature, present commonalities in the studies, identify gaps and discuss opportunities for further research in the area.

**INDEX TERMS** Cloud computing, the industrial IoT (IIoT), the Internet of Things (IoT), service-level agreements (SLA), SLA definition, SLA modeling, systematic literature review.

## I. INTRODUCTION

Cloud computing is a computing model that allows the users to access massive amount of virtualized computing resources as on-demand services [1]. It provides access to the information and data from anywhere at any time by restricting or eliminating the need for hardware equipment. Cloud Computing can be used to foster the ''Internet of Things'' (IoT), which introduces another dimension on top of the computing resources to include physical devices, i.e., the ''things'' [2]–[4]. There is a growing trend to integrate IoT with cloud computing as this combination provides many new opportunities, allows for new applications, more flexible business models. However, a number of new challenges arise with cloud computing. In particular, since consumers have little control over hardware placed in the cloud, one challenge is concerned with ensuring quality of service through Service Level Agreements (SLAs) in cloud-based services in the context of IoT.

This work follows previous research which points towards the lack of standardization of SLAs. In particular, the systematic literature study by Faniyi and Bahsoon in [5] highlights that almost no research builds on the SLA standards such as Web Services Agreement (WS-Agreement) and Web Service Level Agreement (WSLA) [6]. Most of SLA templates are today ad-hoc; e.g., [7] shows how differently various cloud service providers formulate their SLAs. The result is further corroborated by the study by Sfondrini *et al.* [8] in which interviews of successful companies using public cloud providers were performed. This study also shows that the

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contemporary solutions for establishing SLAs are insufficient as they provide a too-low degree of control and a lack of transparency on the actual performance of the services.

In a previous work [9] we investigated the current state-of-the-art on management of SLAs in IoT through a systematic mapping study. That study identified that the research on definition and modeling of SLAs for cloud services in IoT is widely dispersed and there is a lack of a systematic and comprehensive literature review. To address this lack of knowledge, this paper builds on top of the previous work [9] to perform a comprehensive systematic review of the definition and modeling aspects of SLAs for cloud services in IoT, which are crucial in establishing SLAs between service providers and consumers. The paper also presents and discusses sub-categorization of SLA definition and modeling. Furthermore, the paper analyzes the extracted relevant literature, presents commonalities in the studies, identifies gaps and discusses opportunities for further research in the area.

The rest of the paper is structured as follows: first, in Section II, we describe the methodology that is used when performing the paper search and data extraction. Next, Section III provides definitions of the evaluation criteria that are adopted when analyzing the papers. After that, Section IV and Section V present the results of the analysis and the following discussion. Previous work that is related to the current paper is addressed in Section VI, while Section VII discusses possible threads to validity of the results. Finally, Section VIII concludes the paper.

## II. METHODOLOGY

This paper builds on top of our previous work in [9], where following the systematic mapping methodology proposed by Petersen et al. in [10], [11] we performed a systematic mapping study of the existing research on the management of SLAs in Cloud-IoT applications. This work resulted in categorizing studied articles into seven groups according to their contributions as shown in Figure 1. This paper specifically focuses on two of the identified categories, namely SLA definition and modeling, by providing a deeper analysis of the contributions on these two aspects. In this section we summarize the steps we followed when performing this systematic literature study.

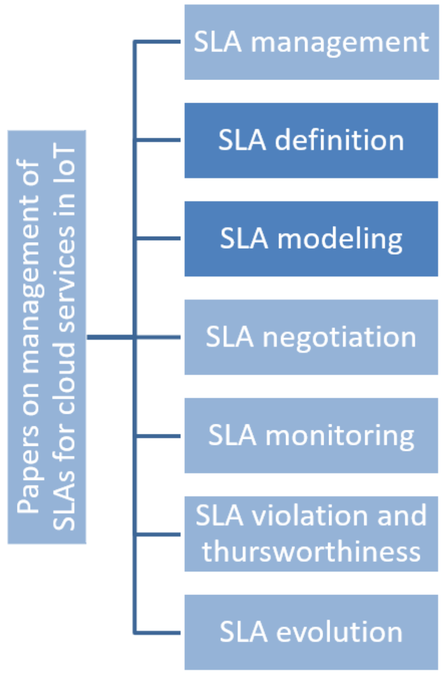


**FIGURE 1.** Original categorization of management of SLAs for cloud services in IoT identified in [9].

### A. GOAL AND CORE RESEARCH QUESTIONS

The main goal of this paper is to perform a comprehensive systematic literature study on the definition and modeling aspects of SLAs for cloud services in IoT. The purpose of this study is to mainly answer the following core research questions in the context of SLAs for cloud services in IoT.

- How expressive are the existing research contributions on modeling and defining SLAs using ontology and languages?
- What kind of frameworks, methodologies and templates have been proposed so far? What types of SLAs do they cover?
- Which specific aspects of SLA definition and modeling, apart from concrete full proposals, attracted attention in the existing research?
- What is the level of formalism, maturity and tool support in the existing contributions in defining and modeling SLAs?

### B. SEARCH AND SELECTION STRATEGY

#### 1) SELECTED DATABASES

We follow the recommendations from [10], [12] and search in the most commonly used databases in Software Engineering and computer science, namely: (i) IEEE Xplore digital library, (ii) Science Direct, (iii) Web of Science, (iv) Scopus, and (v) ACM Digital Library.

#### 2) SEARCH TERMS

As explained in [2]–[4], IoT extends cloud computing by taking physical devices into account. We, thus, use the search string below to find relevant publications on SLAs related to cloud computing and IoT. Furthermore, to be inclusive and not miss relevant publications in the study, we also include the terms "*sla*" (service level agreement), "*iot*" (internet of things), "*industrial internet of things*" and "*iiot*" (industrial internet of things) in the search string, which we then manually adapt in the function of the syntax used by various databases. We use the following search string:

("service level agreement" OR sla) AND ("internet of things" OR iot OR "industrial internet of things" OR iiot OR "cloud computing")

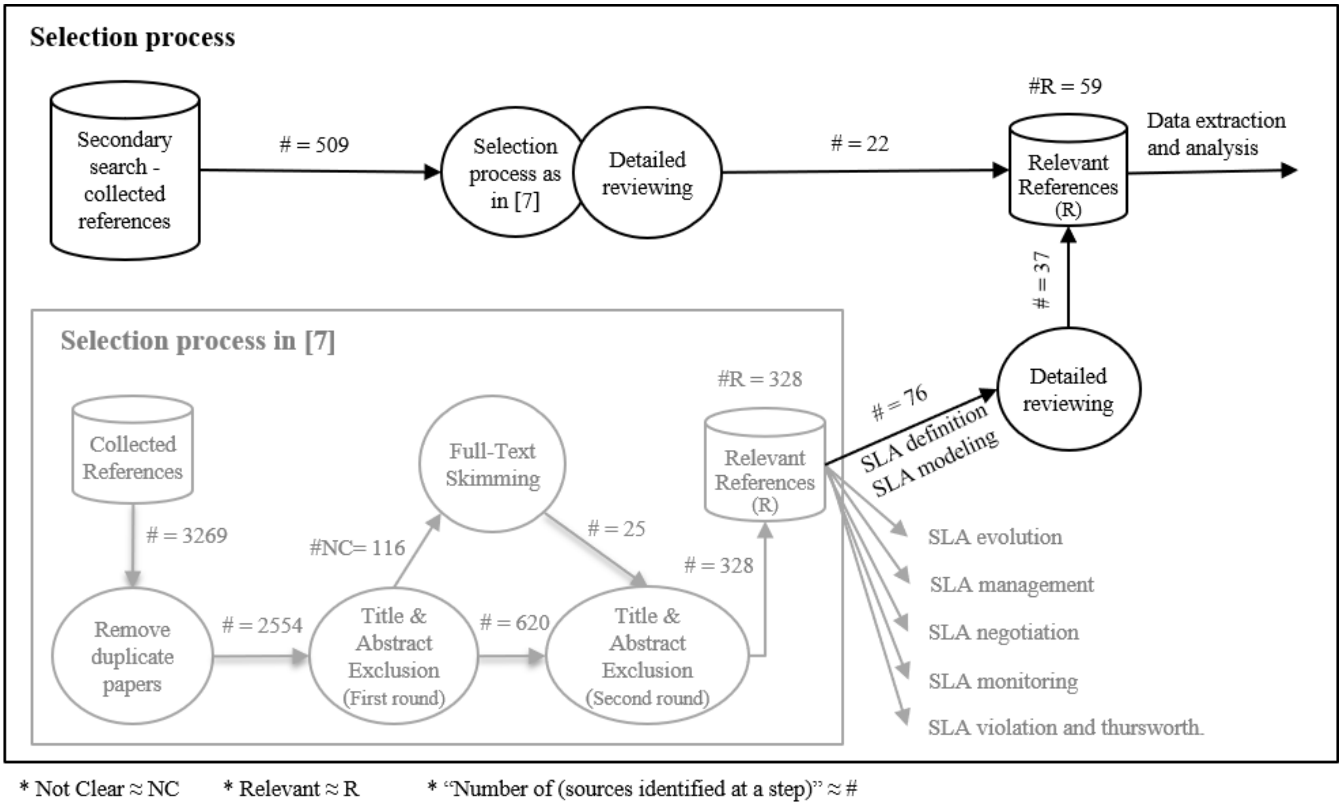


**FIGURE 2.** Selection process for the systematic literature study.

Note, that the pool of searched results correspond to the publications until October 2018.

#### 3) INCLUSION CRITERIA

We use the following list of Inclusion Criteria (IC) to analyze if a searched study should be selected for data extraction and further analysis.

- (IC1) The searched study addresses definition or modeling of SLAs for cloud services in IoT.
- (IC2) The searched study is peer-reviewed in the form of a journal, conference, workshop publication or a book chapter.
- (IC3) The searched study is written in English.

#### 4) EXCLUSION CRITERIA

The following list of Exclusion Criteria (EC) is used to analyze if a searched publication is excluded from the study.

- (EC1) The searched study is a PhD dissertation, book, abstract or is not a scientific publication (e.g., white paper).
- (EC2) The searched study is not available in full text.

### C. SELECTION PROCESS

We use a two-step selection process to identify relevant publications in our study as shown in Figure 2. In the first step, we collect relevant studies from the systematic selection process conducted in [9], which is depicted by the gray-marked steps in Figure 2. From the initially collected 3269 possibly relevant publications, 715 duplicate publications were identified and removed, leading to 2554 publications left in the pool. Next, the inclusion and exclusion criteria were applied based on reading the titles and abstracts of the remaining studies in the pool to classify them into three categories by using adaptive reading depth technique as specified in [12]. *Relevant* gathers all publications related to SLAs in Cloud-IoT. Publications not primarily concerning with the topic of SLAs in Cloud-IoT are sorted under *Not Relevant*. Publications for which titles and abstracts were not sufficient to conclude on their relevance were grouped as *Not Clear*. It is important to note that the inclusion criteria (IC1) in the first step is more generic in the sense that it deems a publication relevant if it addresses SLAs in Cloud-IoT, unlike IC1 in the second step that regards a publication relevant if it addresses definition or modeling of SLAs in Cloud-IoT. The first step resulted in 620 Relevant, 1818 Not-Relevant and 116 Not-Clear publications that went through an extra round of full-text skimming. At this stage 645 (620 + 25 marked as Relevant after full-text skimming) publications were collected. It was found during the first round that many publications marked as Relevant focus on scheduling and resource management for cloud services, whereas the management of SLAs in IoT applications, the main focus of [9], was only slightly discussed. Thus, second round of title and abstract exclusion was performed filtering out publications targeting scheduling and resource management. After this step, the total number of relevant publications was equal to 328. Then, during the systematic mapping study in [9], the relevant publications were sorted according to seven categories: SLA management, SLA Definition, SLA Modeling, SLA Negotiation, SLA Monitoring, SLA Violation & Trustworthiness, and SLA Evolution. Since the main focus of this paper is on definition and modeling of SLAs for cloud services in IoT, the second step in the selection process shortlisted 76 publications out of 328 identified studies in [9] as shown in Figure 2. These publications went through a round of detailed full-text reviewing, after which 37 publications matching the goal and core research questions (discussed in Section II-A) of this study were identified. Continuing with the second step, we repeated the aforementioned process from [9] for the studies published during the years 2017 and 2018 to have a complete and up-to-date list of relevant publications. This secondary search and following selection process resulted in 22 relevant publications. Thus, in total as a result of the two-step systematic selection process, 59 relevant publications were selected to be included in this study as shown in Figure 2. Finally, during the data extraction and interpretation, 15 publications were discarded after detailed reviewing and analysis of the publications. Therefore, the final list of studies included in this study consists of 44 publications.

### D. DATA EXTRACTION

To perform the data extraction, a questionnaire was created to be filled in for every paper. First, we tested the questions on a subset of papers. Each author answered the questions from the questionnaire in natural language; no restriction was placed on the formulation of the answers as the purpose was to refine the questionnaire and harmonize the authors' understanding of the questions. Other interesting observations about each paper and possible additional questions for the study were also collected. Based on the initial outcomes, the questions were then revised and whenever possible lists of authorized values for each question were established. The questions included information about the degree of formalization, details weather the contribution is domain-specific or not, if it is supported by tool(s), and level of maturity of the contribution presented in the publication. The core contents of the questionnaire and details regarding the definitions of the terms and possible choices are presented as part of the evaluation criteria in Section III. The data were then extracted in a spreadsheet according to the questionnaire with one question per column with predefined answer values if applicable. Furthermore, Paper ID, Title, Authors, publication venue, publication year, publication type were also recorded.

### E. CLASSIFICATION SCHEME

Based on the full-text reviewing of the final set of relevant studies, it was observed that the these studies can be grouped according to specific aspects of SLA definition and modeling. The resulting classification scheme is depicted in Figure 3.

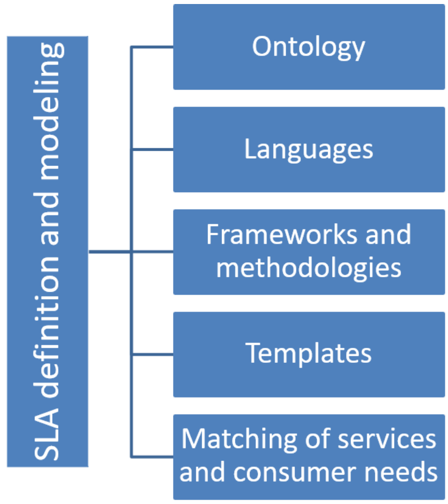


**FIGURE 3. Classification scheme.**

- *Ontology:* This category encompasses works with the main contribution on how best to write SLAs by defining through an ontology the key components that an SLA should contain.
- *Languages:* The studies in this category focus on presenting a new language or extension of an existing language to define or model SLAs for cloud services in IoT.
- *Frameworks and methodologies:* This category brings together the studies that look at SLA creation from a higher level and provide frameworks for SLAs, e.g., SLAs for mobile services, or methodologies for SLA creation.
- *Templates:* The studies grouped in this category provide templates for SLAs that range from general ones, to specific parts of SLAs or SLAs for specific applications.
- *Matching of services and consumer needs:* This category covers the studies that focus on specific aspects that are crucial for SLA definition. These specific topics include definition of parameters that are important to be included in SLAs, models for defining the relationships between price and quality of provided service, and methods for automating data extraction from various SLAs.

## III. EVALUATION CRITERIA

This section provides definitions of various elements that are used to structure the identified existing works on modeling and definition of SLAs. These elements also form the core contents of the questionnaire that is used to analyze the relevant studies.

### A. MAIN CONTENTS OF AN SLA

First, let us look at the main parts that should be included in every SLA.

*Service Name and Description*: An SLA provides the name and detailed description of each service that is offered to the service consumer by the service provider.

*Parties Description*: An SLA explicitly provides detailed description of the parties who come into aggreement according to the SLA. The parties may include one or more service providers and one or more service consumers. A party could be a private, commercial or a public entity. *Service Level Indicator*: Service Level Indicator (SLI) is a parameter or a metric associated to a service that is used to specify or determine a certain quantitative or qualitative quality of service. SLI's are also referred to as the SLA parameters or metrics. Examples of SLI's inlcude availability, latency, response time, jitter, scalability, processing capacity, memory, storage, among others [13].

*Quality of Service Description of SLI*: Quality of Service (QoS) description of an SLI provides its quantitative or quaitative description. In other words, the QoS description of an SLI may refer to the details that describe the domain and span of the SLI. For example, consider the availability SLI. The QoS description of availability may refer to "all-time availability", 24-hour availability, weekly availability, and/or availability in different intervals (e.g., weekdays, weekends). This description may also support different Service Level Objective (SLOs) for the same SLI in different spans or durations.

*Service Level Objective*: A Service Level Objective represents a threshold or a value on an SLI or a metric. Basically, an SLO depicts the commitment of the service provider to the consumer on a particular service [14], [15].

*Composite SLI*: Some languages or frameworks for modeling of SLAs allow to aggregate more than one SLI. Such an aggregated SLI is called a composite SLI [14]. Each composite SLI has a set of associated SLOs, which could be an aggregation of the SLOs of the individual SLIs. Alternatively, an SLO can be defined for the composite metric independently from the constituting SLIs.

*Penalty*: Penalty refers to the fine that the service provider is obliged to pay to the service consumer if the SLO specified on an associated SLI is not met. For example, a service provider guarantees to provide 99% availability of a service. If the service availability falls below 99% during an agreed upon interval (e.g., a day, a week or a month) then the service provider is obliged to compensate the consumer according to the agreed upon terms stated in the SLA. The compensation could be paid directly as a fine or indirectly deducted from the service charges.

### B. DEGREE OF FORMALIZATION

The degree of formalization of ontology, languages or templates for writing SLAs may range from completely unstructured documents written in natural language to formal specification. The degree of formalization is classified in three different categories: (i) unstructured, (ii) semi-structured, and (iii) formal.

- *Unstructured.* In this category, there is no structure provided to write the template. The SLA document is written in natural language in ad-hoc manner.
- *Semi-structured.* A limited structure, in the form of a template for example, is used to describe the SLA. Key elements that the SLA should contain are listed. However, limited information (if any) is given on how those elements should be specified. Generally, the key elements are described in a natural language.
- *Formal*. In comparison to the previous categories, a clear structure is provided and the elements are formally described. Several methods might be used to formally describe an SLA: using an ontology, a mathematical notation (e.g., statecharts, Petri Nets), etc. In addition to syntactical specification, semantics and/or behavioral specification might also be provided.

### C. LEVEL OF MATURITY

The level of maturity of the proposed technical contribution (ontology, language, technique, methodology, framework or a tool) in each publication is described with respect to the maturity classification in the Redwine-Riddle model [16]. According to this classification, a contribution can be considered (i) "not mature at all" if basic ideas are presented and there is no proof of concept, (ii) "somewhat mature" if the contribution is thoroughly discussed together with a proof of concept and the usability of the contribution is demonstrated on use cases, (iii) "mature" if the contribution is thoroughly discussed together with a proof of concept, the usability of the contribution is demonstrated on use cases and the contribution is used or adapted by the research community, and (iv) inconclusive if the contribution cannot be categorized with respect to the previous three points.

### D. TOOL SUPPORT

Moreover, for each studied paper we are interested in identifying whether its contribution to modeling and definition of SLAs is supported by a tool or not. In case of the contribution being supported by a tool, we further analyze if the supported tool is a freeware, open source and/or proprietary tool. This is especially interesting in case of contributions that correspond to modeling languages, methodologies and frameworks for the definition and modeling of SLAs.

### E. APPLICATION DOMAIN

The technical contributions in each paper are also analyzed with respect to the application domain. A contribution in a paper (e.g., language or methodology for modeling and definition of SLAs) could be generally applicable within the area of cloud services in IoT or be tailored to a specific application domain within this area, e.g., E-commerce [17], transportation and logistics services [18], E-learning [19], Mobile web services [20], to mention a few.

**TABLE 1.** Level of expressiveness in the ontology for SLAs discussed in the relevant publications.

| Paper ID | Year | Service Name | Service Description | Parties Description | Service Level Indicator (SLI) | QoS Description of SLI | Service Level Objective (SLO) | Composite SLIs | Penalty |
|---|---|---|---|---|---|---|---|---|---|
| García et al. [22] | 2017 | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Labidi et al. [23] | 2018 | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | – | ✓ |
| Rady et al. [24] | 2013 | – | ✓ | – | ✓ | – | – | ✓ | – |
| Labidi et al. [25] | 2017 | ✓ | – | – | ✓ | ✓ | ✓ | – | ✓ |
| Rady et al. [26] | 2014 | ✓ | ✓ | ✓ | – | – | – | – | – |
| Alhamad et al. [13] | 2010 | – | – | – | ✓ | ✓ | ✓ | – | – |
| Di Modica et al. [27] | 2012 | – | ✓ | ✓ | ✓ | – | – | – | – |

## IV. DATA EXTRACTION AND ANALYSIS

In this section we provide the results from the data extraction. We describe the papers group by group, according to the classification discussed in Section II. For every group, we briefly cover the content of the contributions, discuss commonalities and differences in the included publications, look at the characteristics such as tool-support, application domain, level of maturity and others.

### A. ONTOLOGY TO DEFINE AND MODEL SLAs

Ontology has various meanings in different context. In computer science, ontology refers to the way of representing the knowledge of a domain where several objects with their relationships are described by a vocabulary [21]. In the context of SLA, ontology refers to a method of providing a taxonomy for an SLA content in order to better understand, define and model the SLA.

In this systematic study, we identify 7 publications that present SLA definitions and modeling based on an ontology and represent different components of SLAs with ontology languages [13], [22]–[27]. Furthermore, we notice that each paper presents SLA's ontology on a different level and with different details. The summary of this investigation is shown in Table 1. The SLA modeling may contain various components that are shown in the columns of Table 1. We observe that only one of the publications, i.e., the work by García *et al.* [22] supports all components of generating an SLA, including an interesting feature of composition of SLIs. Next, Labidi *et al.* [23] cover the second highest number of the components in SLAs by considering all the components except for the composite SLIs. In general, only two of the works, i.e., García *et al.* [22] and Rady [24], identify composite SLIs as one of the features in SLA definition, while the rest of the publications only focus on individual SLIs. Another interesting observation is that only 3 of the relevant publications consider penalty aspects in the ontology-based SLA definitions, which are the works by García *et al.* [22], Labidi *et al.* [23] and Labidi *et al.* [25]. Furthermore, most of the published works include the component of SLIs in the ontology, except for the work by Rady [26].

The extracted data from the surveyed papers in this category also show that most of the contributions in the identified publications are formal based on a formal ontology specification as presented in Table 3. Moreover, the contributions are somewhat mature. In fact, only one publication, the work by Alhamad *et al.* [13], lacks this formalism in the presentation of contributions and is *not mature*. This is mainly because this work is a short paper with initial ideas and investigation. Another observation is that all publications in this category target general domain without specifying a special use case for a domain-specific application. As a part of the contributions, some of the works develop or extend a tool for SLA definition and modeling. We identify that the publications [22], [23], [25] and [27] provide tools to support or evaluate their methods, namely IDEAS software simulation framework-based tool, Cloud SLA Analyzing (CSL2A) tool, CSLA2M tool and Ontology Mapper tool respectively. The tools are published in different forms. For example, [22] and [23] provide the tool in proprietary form, whereas [25] and [27] support freeware tools.

### B. LANGUAGES TO DEFINE AND MODEL SLAs

The systematic investigation of the state of the art performed in this paper identified 8 publications that mainly focus on presenting a new language or extension of an existing language to define and model SLAs [14], [28]–[34]. For instance, Serrano *et al.* [28] present the Cloud Service Level Agreement (CSLA) language, while Hasan *et al.* [29] extend this language to support Green SLAs. Similarly, Uriarte *et al.* present the SLAC langauge for SLAs in [30] and its extension in [31]. Furthermore, the WSLA, S3LACC, RSLA and XClang languages for modelling SLAs are presented by Longo *et al.* [32], Ghumman and Schill [33], Tata *et al.* [14], and Stamatakis and Papaemmanouil [34] respectively. An analysis of the above mentioned works reveals that there is a variation in the utilization of the full expressiveness of these languages with respect to the specification of various aspects of SLAs.

Table 2 summarizes the level of support in all the relevant publications to specify and describe the necessary elements of an SLA. Apart from [32], no other study supports all the necessary elements to fully describe an SLA. There are only two studies [32], [33] that can specify composite SLIs in an SLA. Furthermore, we note that the contributions on SLA

**TABLE 2.** Level of expressiveness in the languages for modeling of SLAs discussed in the relevant publications.

| Paper ID | Year | Service Name | Service Description | Parties Description | Service Level Indicator (SLI) | QoS Description of SLI | Service Level Objective (SLO) | Composite SLIs | Penalty |
|---|---|---|---|---|---|---|---|---|---|
| Serrano et al. [28] | 2013 | – | ✓ | – | – | ✓ | ✓ | – | ✓ |
| Hasan et al. [29] | 2017 | ✓ | ✓ | ✓ | – | – | – | – | – |
| Uriarte et al. [30] | 2014 | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | – | ✓ |
| Uriarte et al. [31] | 2016 | ✓ | – | ✓ | ✓ | ✓ | – | – | – |
| García et al. [32] | 2015 | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Schill et al. [33] | 2017 | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | – | – |
| Tata et al. [14] | 2016 | ✓ | ✓ | – | ✓ | – | ✓ | ✓ | ✓ |
| Papaemmanouil et al. [34] | 2014 | – | – | – | ✓ | ✓ | ✓ | – | – |

**TABLE 3.** Characteristics of languages and ontology addressed in the relevant publications.

| Focus | Paper ID | Year | Level of formalism | Tool support | Application Domain | Maturity level |
|---|---|---|---|---|---|---|
| Ontology | García et al. [22] | 2017 | Formal | Proprietary | General | Somewhat mature |
| | Labidi et al. [23] | 2018 | Formal | Proprietary | General | Somewhat mature |
| | Rady et al. [24] | 2013 | Formal | No | General | Somewhat mature |
| | Labidi et al. [25] | 2017 | Formal | Freeware | Generic | Somewhat mature |
| | Rady et al. [26] | 2014 | Formal | No | General | Somewhat mature |
| | Alhamad et al. [13] | 2010 | Informal | No | General | Not mature |
| | Di Modica et al. [27] | 2012 | Formal | Freeware | General | Not mature |
| Languages | Serrano et al. [28] | 2013 | Semi-structured | Open source | General | Mature |
| | Hasan et al. [29] | 2017 | Formal | No | General | Somewhat mature |
| | Uriarte et al. [30] | 2014 | Formal | Open source | General | Somewhat mature |
| | Uriarte et al. [31] | 2016 | Formal | Open source | General | Mature |
| | García et al. [32] | 2015 | Semi-structured | Other (in-house) | General | Somewhat mature |
| | Schill et al. [33] | 2017 | Formal | No | General | Not mature |
| | Tata et al. [14] | 2016 | Formal | No | General | Somewhat mature |
| | Papaemmanouil et al. [34] | 2014 | Semi-structured | Freeware | General | Not mature |

writing are often introduced together with additional mechanisms to complement the language itself. In [22], [30], SLA analysis operations are provided which aim at evaluating SLA feasibility, validation and verification, including detection of possible violations and monitoring mechanisms.

The analysis of the extracted data reveals that the degree of formalization in the SLA languages differs significantly between the contributions of the relevant papers as shown in Table 3. The degree of formalization in these works ranges from *semi-structured* documents written in natural language [28], [32], [34] to *formal* specification [14], [29]–[31], [33]. It is interesting to note that 62.5% of the total relevant publications on languages for modeling SLAs present *formal* contributions, whereas the remaining 37.5% of the publications provide *semi-structured* contributions. The SLA documents that are written by service providers in a natural language, often simply by textual description of the terms and conditions, result in SLAs being complex, ambiguous and often incomplete. Furthermore, this restricts the possibility for automation such as monitoring, automated error resolution, and services interoperability.

We also note that not all contributions in the relevant publications on languages for SLA modeling are supported by tools as shown in Table 3. There are only three contributions [28], [30], [31] that complement the SLA modeling languages with open-source tools, one contribution [34] that complements the SLA modeling language with freeware tools. Another contribution [32] is supported by an in-house tool that is not available publicly. Surprisingly, none of the contributions in the relevant publications on languages for SLA modeling is domain-specific. In fact, all of the languages are developed for writing general-purpose SLAs. Finally, we note that apart from the two contributions [28], [31], none of the other contributions on languages for SLA modeling are fully mature according to the Redwine-Riddle model [16]. The contributions in [14], [29], [30], [32] are *somewhat mature*, while the contributions in [33], [34] are *not mature* as depicted in Table 3.

### C. FRAMEWORKS AND METHODOLOGIES TO DEFINE AND MODEL SLAs

The systematic investigation of the literature identified a number of publications that address definition and modeling of SLAs at a higher level of abstraction compared to the languages for defining SLAs. These publications mainly propose frameworks and methodologies to develop SLAs. Among them, the work in [20] argues that mobile devices are starting to offer their resources as mobile Web Services and

**TABLE 4. Characteristics of frameworks and methodologies in the relevant publications.**

| Paper ID | Year | Level of formalism | Tool support | Application Domain | Maturity level |
|---|---|---|---|---|---|
| Aijad et al. [20] | 2010 | Unstructured | No | Mobile Web services | Not mature |
| Busalim et al. [17] | 2013 | Unstructured | No | E-commerce | Not mature |
| Motta et al. [35] | 2013 | Semi-structured | No | General | Not mature |
| Longo et al. [36] | 2013 | Unstructured | No | General | Not mature |
| Stamou [37] | 2014 | Semi-structured | No | General | Somewhat mature |
| Boukadi et al. [38] | 2016 | Semi-structured | No | General | Not mature |
| Spillner et al. [39] | 2009 | Unstructured | No | General | Not mature |
| Saadaoui et al. [40] | 2017 | Formal | Open source | General | Somewhat mature |
| Casola et al. [41] | 2016 | Semi-structured | No | Web services | Mature |
| Casola et al. [42] | 2015 | Semi-structured | No | General | Not mature |

consequently these services should also be covered by SLAs. Thus, the authors provide an SLA framework for mobile devices as a specific domain. Similarly, another framework for a concrete application domain, E-commerce, is provided in [17]. This framework is based on the lifecyle of WSLA language and is able to provide holistic guarantees of the QoS of the offered services to the end users. The QoS concepts are discussed for different services, such as IT, Cloud and business, in [35]. The discussion leads to identifying the main differences of QoS in Cloud and other sectors, and finally provides a framework to establish QoS parameters and descriptions in an SLA.

Looking at methodologies, the authors of [36] cover composition of services in creating SLAs. Moreover, since SLAs contain large amounts of information that should be systematically stored for better modularity and data accuracy, the work in [37] presents a methodology to manage SLA information by defining a database with formal semantics. Next, the process of establishing SLAs between the service providers and consumers is automated by Boukadi *et al.* in [38]. In this regard, the authors provide a method to compose the requested services along with their QoS constraints and preferences as part of the SLAs. Moreover, the work in [39] describes a methodology for dynamic SLA adjustment.

One of the important aspects that need to be considered in SLAs to protect the service providers and consumers is security property. The work in [40] proposes a framework to specify requirements of web services using the WSLA Language. The proposed framework is able to generate web services policy documents based on web service security requirements. The authors concentrate on three aspects of web service security, namely transport security, user authentication, and message encryption. Similarly, the work in [41] focuses on security guarantees that are offered to the service consumers according to their particular needs and are related to specific service instances. Furthermore, the authors of [41] investigate the adoption of the cloud service customers-based per-service SLA model. The deployment of the supporting software can be implemented automatically for automated software management. The authors provide a platform-as-a-service to develop SLA-based secure cloud security services and promote security-by-design in multi-cloud application contexts through the adoption of SLAs. Moreover to foster the adoption of security SLAs, the work in [42] proposes a framework that offers security assurance to cloud customers, by managing the lifecycle of agreed security parameters contained in SLAs. The security features are automatically implemented by the proposed framework according to the agreed SLA, and can be continuously monitored to verify that the SLA terms are respected.

Looking at the data extraction for relevant publications on frameworks and methodologies for modeling and definition of SLAs in Table 4, we observe that only one contribution provides a tool support, i.e., [40]. The supported tool is an open-source software that can be used by other researchers. Another interesting observation is that most of the methodologies are proposed for general purpose applications and only few works define frameworks for specific applications, such as [20] and [41] for web services, and [17] for e-commerce applications. Furthermore, most of the works are *not mature*, according to the Redwine-Riddle model [16], except the work in [41] for web service applications. The investigation shows that there is a clear need for providing proof of concept for the proposed methodologies and frameworks for the modeling and definition of SLAs for cloud serivces in IoT.

### D. TEMPLATES TO DEFINE AND MODEL SLAs

In this section we present the papers which provide concrete templates of models for SLA creation. When studying the publications in this category in more details, we see that the papers in this category can be further split according to the coverage area of the template they present. Thus, the following description starts with Group 1 - general templates, then moves to Group 2 presenting templates for a general application area, but a specific part of an SLA or an SLA of a specific type. Finally, Group 3 covers the articles presenting templates for concrete application domains.

#### 1) GROUP 1: GENERAL TEMPLATES

In order to settle an SLA between two parties, normally an SLA template should be used. The SLA templates are often provided by the service provider, hence not many aspects and metrics are addressed. In order to formalize and model such templates, several works have addressed methods to create SLA templates with various contents that can be incorporated. For instance, the work in [43] presents a modeling approach for SLAs based on UML. The model provides necessary elements of an SLA, including SLOs and QoS descriptions. Similarly, the work in [44] provides a method to create an SLA template to be used for negotiation phase between service provider and service consumer. In the latter work, the pricing factors to describe profit and loss of the two parties are also included. Moreover, the latter work conducts a case study to evaluate the impact of faults on the provider profits. Longo *et al.* [15] present a conceptual model for developing SLAs. Using this model they propose a formal template based on the UML language to support the modeling of SLAs. Breskovic *et al.* [45] provide an adaptive approach to automatically adapt public SLA templates based on user requirements. Maurer *et al.* [46] formalize public SLA template life cycle which consists of 5 steps: (i) creating initial template, (ii) mapping of SLA to the consumer's private SLA template, (iii) identification of the consumer needs by the service provider, (iv) adaptation of the template based on step (iii), and (v) creation of the final SLA template based on the previous steps. Similarly, Kamel *et al.* [47] use the Bigraphical Reactive Systems (BRS) approach to develop formal models of customers, services, SLAs, and relations among these entities. A set of reaction rules is proposed to show the evolution of their states during the different stages of the SLAs lifecycle. The paper shows that the proposed models can be applied at any level of cloud computing architectures, including SaaS, PaaS, and IaaS.

#### 2) GROUP 2: GENERAL TEMPLATES, BUT FOR SPECIFIC PART OF AN SLA/TYPE OF AN SLA

We notice that some of the papers look at specific aspects of SLA templates. For example, Su *et al.* [48] adopt Cloud Bank (CB) model as a resource management model and look specifically at liquidity risks (i.e., absence in the bank of the resources asked for by the consumer), define the parameters describing the QoS and provide a template for CB-Risk-SLA. Next, the work in [49] introduces and examines the basic notion and concept of Green Service Level Agreements (GreenSLAs). As such, it provides an introduction to the field and initial ideas. By examining common energy saving strategies and analyzing their impact on the QoS perceived by the customers, the paper identifies SLA parameters that have to be interpreted and utilized. Based on the findings, the paper develops an XML-based specification mechanism and process which is machine-interpretable and can be verified in a semi-formal way. The proposal helps to monitor energy consumption in order to provide green SLA metrics. Discussing more on specific types of SLAs, Rak [50] propose a technique to automatically generate the composed security SLA relying on a cloud service provider declaration and the provided services that compose the application. Security SLAs and cloud applications are modeled, enabling automatic reasoning over the security offerings and the evaluation of the security policy over orchestration of cloud services. Finally, Casola *et al.* [51] present a security metric catalogue for SLA to formalize security metrics and security-oriented SLOs. The catalogue can be used to monitor the level of security provided by a cloud or multi-cloud application. It collects some of the security metrics based on their previous projects and existing standard initiatives and scientific literature.

#### 3) GROUP 3: TEMPLATES FOR SPECIFIC APPLICATION DOMAINS

Several researchers have proposed SLA templates with the focus on concrete application domains. For example, Marquezan *et al.* [18] look at transport and logistics services and after describing specifics of the field and introducing an additional level of detail when writing SLAs for logistics services – a frame SLA, the authors provide a model for all the data that can be included in an SLA for transport services. Additionally, the authors implement a dedicated user interface for SLA management using the proposed data model including information from specific SLAs, frame SLAs and QoS monitoring data. Next, the work in [19] deals with SLAs for a cloud-based e-learning system, looks at the parameters of interest for the application, the involved parties, dependencies between them and needed SLAs. The third publication addressing SLAs for a specific domain is Kapassa *et al.* [52], which proposes an SLA management framework for 5G networks. Here, the idea is to first generate the SLA templates for the service or the infrastructure provider, and then create the final SLA. The generator obtains a set of policies for the specific network services such that the generated template is in the human-readable format and is immediately available to the service or infrastructure provider.

Table 5 summarizes the characteristics of the contributions providing various SLA templates. Looking at the level of formalism, we can see that most of the papers are *formal*, two are *semi-structured* and only three are *unstructured*. Moreover, half of the contributions reach at least *somewhat mature* level according to the Redwine-Riddle model [16]. However, only the authors of [18] provide a tool to support their proposed data model.

### E. MATCHING OF SERVICES AND CONSUMER NEEDS IN SLA ESTABLISHMENT

In our study we also identify a group of papers that address different aspects of modeling and definition of SLAs. In contrast to the publications discussed above that present ontology and languages to write an SLA or provide complete templates or models, the papers in this section specifically focus on matching of consumer requirements and services and the level of offerings by the service providers, which have an important role in establishing the SLAs between the service providers and consumers. Table 6 shows the relevant publications and the corresponding areas with respect to the included contributions.

**TABLE 5. Characteristics of templates in the relevant publications.**

| Group ID | Paper ID | Year | Level of formalism | Tool support | Application Domain | Maturity level |
|---|---|---|---|---|---|---|
| Group 1 | Ayadi et al. [43] | 2013 | Semi-structured | No | General | Not mature |
| | Freitas et al. [44] | 2012 | Formal | No | General | Mature |
| | Longo et al. [15] | 2018 | Formal | No | General | Not mature |
| | Breskovic et al. [45] | 2011 | Formal | No | General | Somewhat mature |
| | Maurer et al. [46] | 2012 | Formal | No | General | Mature |
| | Kamel et al. [47] | 2017 | Formal | No | General | Somewhat mature |
| Group 2 | Su et al. [48] | 2012 | Formal | No | General | Not mature |
| | Klingert et al. [49] | 2011 | Unstructured | No | General | Somewhat mature |
| | Rak et al. [50] | 2017 | Formal | No | General | Somewhat mature |
| | Casola et al. [51] | 2017 | Unstructured | No | General | Not mature |
| Group 3 | Marquezan et al. [18] | 2014 | Semi-structured | Open source | Transport and logistics services | Somewhat mature |
| | Elmatary et al. [19] | 2015 | Unstructured | No | E-learning | Not mature |
| | Kapassa et al. [52] | 2018 | Unstructured | No | 5G Networks | Not mature |

**TABLE 6. Matching of services and consumer needs in SLA establishment.**

| Paper ID | Year | Parameter of interest per service type | Cost and service relationship model | Information extraction from an SLA |
|---|---|---|---|---|
| Rady [53] | 2012 | ✓ | – | – |
| Dogra et al. [54] | 2017 | ✓ | – | – |
| Talal et al. [55] | 2018 | ✓ | – | – |
| Maurer et al. [46] | 2012 | – | ✓ | – |
| Christ et al. [56] | 2017 | – | ✓ | – |
| De Marco et al. [57] | 2016 | – | – | ✓ |
| Mittal et al. [58] | 2017 | – | – | ✓ |

First, we can see that the publications in this set address the problem of selection of parameters that are crucial for a service that is covered by an SLA. Among these publications, [53] argues that SLAs are often written in a generic way and thus do not cover specific non-functional requirements (NFRs) that can be important for various service types. Thus, the authors look at the related literature and extract NFRs that are listed as important for different kinds of cloud services and then, having the full list, provide recommendations of NFRs that are specifically important for IaaS, Saas and PaaS. Next, we infer that two of the relevant publications in this category focus specifically on security property in SLAs. Dogra *et al.* [54] propose an architectural and conceptual framework to evaluate the adherence of security policies. The proposed architecture contains a set of security SLAs which can be used to monitor cloud infrastructure for run-time security adherence by a trusted third party on behalf of cloud customers. The authors propose a run-time monitor to observe the system log(s) and then export them to the trusted third party, which can then store and audit the exported log(s). In the same context, Halabi and Bellaïche [55] introduce a broker-based framework to manage cloud security. They analyze the security services that are usually deployed to protect the data and infrastructure from the threats and incidents associated to the cloud; evaluate the security-SLA based on availability, integrity, and confidentiality attributes. The authors also propose a model for security-SLA monitoring, violation prediction, and remediation process to minimize the damage caused by security violations and conflicts.

Next, column two in Table 6 shows which publication looked specifically at the relationships between the cost structures and service levels. The work in [56] addresses this aspect by providing a rule of thumb that enables the system engineers to either calculate the cost-optimal service level to purchase from a known cost-structure or estimate the assumed cost-structure from actual service levels. Also, Maurer *et al.* [46] facilitate the service consumers to perform SLA mapping to their private SLA templates. This mapping, in turn, allows to learn and highlight concrete needs of the consumers which can assist in establishing well-defined SLAs with respect to the consumers' needs and service offerings by the service providers.

The last column in Table 6 hosts the publications that deal with information extraction from a written SLA. Interestingly, only two publications [57], [58] focus solely on information extraction from existing SLAs. Although these two publications do not address definition or modeling of SLAs, we decided to include them in this study as they provide methods for reading and analyzing already established SLAs. Since SLAs are often written in a natural language, they are very hard to analyze automatically, e.g., for monitoring, which is essential part of SLA's lifecycle, or for comparison of the offers and service selection. The work in [57] presents a method to automatically extract the information that is needed for monitoring of SLAs written in a natural language, while the authors of [58] propose a cognitive assistant that can help users to evaluate different cloud services and their performance by analyzing legal documents associated with

**TABLE 7.** Characteristics of contributions within that "Matching of services and consumer needs" category.

| Paper ID | Year | Tool support | Application domain | Maturity level |
|---|---|---|---|---|
| Rady [53] | 2012 | no | General | Not mature |
| Maurer et al. [46] | 2012 | no | General | Mature |
| Dogra et al. [54] | 2017 | no | General | Not mature |
| Talal et al. [55] | 2018 | no | General | Not mature |
| Christ et al. [56] | 2017 | no | General | Not mature |
| De Marco et al. [57] | 2016 | no | General | Somewhat mature |
| Mittal et al. [58] | 2017 | no | General | Not mature |

cloud services and answering natural language queries. These methods make it possible to automatically read and analyze SLAs written using different templates and languages. Without the possibility of an automated analysis, SLA languages and templates would have to be standardized or analyzed manually.

Looking at all the papers in this category taken together, we can see that all of the contributions can be applied to the domain in general as shown in Table 7. However, only Marco *et al.* [57] and Maurer *et al.* [46] reach *somewhat mature* and *mature* levels of contribution respectively. Note that the work by Maurer *et al.* [46] is put in two categories as the authors also formalize a public SLA template life cycle. Moreover, Table 7 shows that no tool support is provided by the papers in this category, which however makes sense as these papers look at different aspects of SLA definition and modeling and not SLAs as a whole.

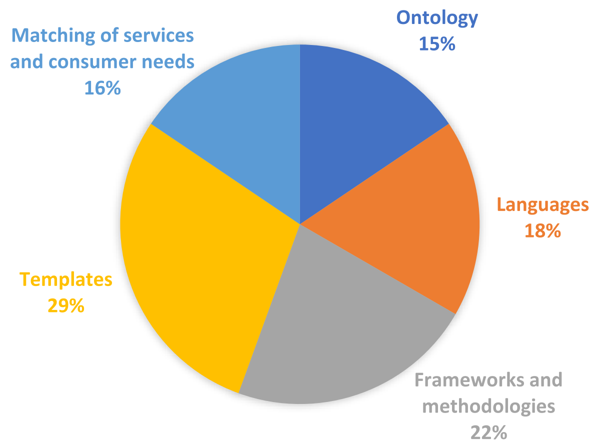


**FIGURE 4.** Identified areas of the contributions. (Note, that the work by Maurer *et al.* [46] belongs to two categories and thus counted two times in the figure.)

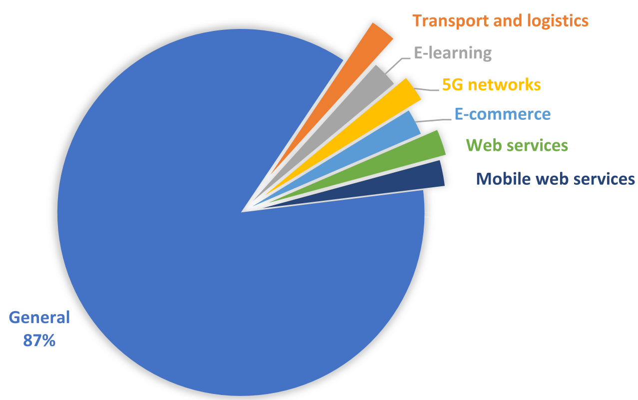


**FIGURE 5.** Application domains of the studied contributions.

## V. DISCUSSIONS

Section IV has presented an analysis of the contributions in the area of SLA definition and modeling for cloud services in IoT. In this section we would like to provide a general summary of the results and point out few more interesting observations.

First, let us look at how the papers are distributed within the identified categories. Figure 4 shows that around third of the contributions on the area of definition and modeling of SLAs provide various sorts of SLA templates. Next, the second biggest group addresses SLAs from a slightly higher level and presents new frameworks and methodologies. Finally, the other three groups have seven to eight contributions each. This distribution shows that all of the identified categories received quite even amount of attention from the research community.

Next, looking at all the publications taken together it is interesting to notice that majority of them are addressing general cloud services and IoT, without specifying concrete application areas. Out of the total of 44 studied publications there are only six papers that target a specific domain that requires SLA development as shown in Figure 5. Interestingly, all domain-specific publications belong only to the frameworks, methodologies and templates. All contributions in the areas of languages and ontology are general, which makes it easier to take the results as they are when applying for concrete needs. However, absence of many concrete domain-specific templates or methodologies can make it harder for consumers to use the templates for their applications without adjustments and adaptations.

Interestingly, out of the six articles presenting concrete domain-specific contributions, only one is characterized as *mature* and one more as *somewhat mature* according to the adopted classification. Taking all the studied contributions together, Figure 6 shows that only five (not six, as [46]

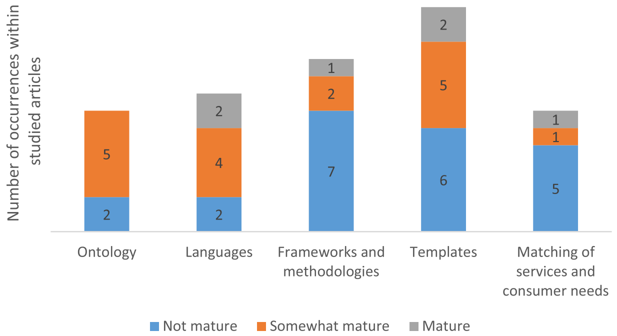


**FIGURE 6.** **Maturity level of the evaluated contributions. (Note, that the work by Maurer *et al.* [46] belongs to two categories and thus counted two times in the figure.)**

appears in the figure in two categories) are at high maturity level, which means that there is still room for future research in the area. At the same time, comparing the maturity level of contributions within the identified categories, one can see the papers presenting languages and ontology for SLAs are on the highest maturity level, followed by the templates for SLAs. Similar trend can be observed when also looking at the level of formalism. It often follows the maturity levels resulting in most of the *formal* contributions reaching at least *somewhat mature* level.

One more metric that is used to characterize the contributions is tool support. Around one quarter of the publications provide a tool for their solutions. Most of the tools are presented for the contributions within the categories of languages and ontology for SLAs. Such wide tool support within these two categories allows easier direct use of the developed languages. Figure 7 shows the distribution of different types of supported tools.

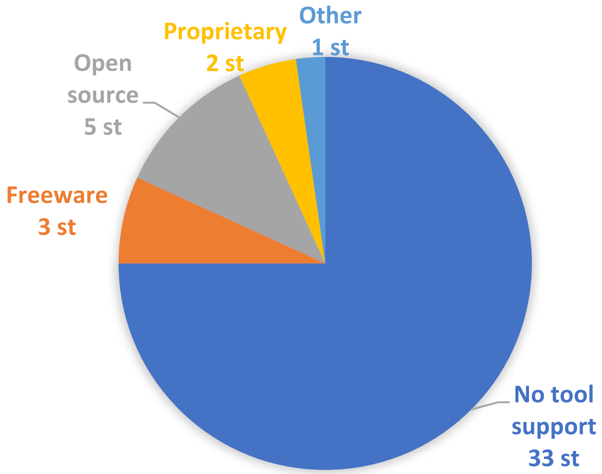


**FIGURE 7.** **Tool support within studied contributions.**

Another interesting trend that can be noted is that in the considered time span of publications, not much attention has been paid to the dynamic features of SLAs. It is foreseen that in the future, with further development of IoT, Fog, cloud services and Industry 4.0, services and processes will be dynamic, allowing for changes and reconfigurations at run-time [59], [60]. To comply with this in a more efficient ways and to avoid interruptions in the services during reconfigurations and re-negotiations, it would be beneficial to consider dynamism already at the stage of SLA definition. We identify that the authors of only three of the analyzed publications address dynamism in their work and look at mechanisms for dynamic SLA modifications. The work in [39] presents a methodology for dynamic SLA adjustments based on the results of run-time monitoring of non-functional properties. The solution suggests that the monitoring output is collected and fed back to the service registry that adjusts service descriptions and provides a template proposal for a new, more precise, agreement (to be manually confirmed). At the same time, Uriarte *et al.* [31] and Labidi *et al.* [23] also investigate the mechanisms for dynamic modifications in SLAs, but from the viewpoint of developing flexible SLAs instead of going through a separate renegotiation process for static SLAs. In the case of unexpected situations or peak loads, the flexibility considered in these works allows the service providers to activate one or more clauses in the SLA to reduce the provided resources (e.g., number of VMs) and offer monetary discounts to the consumer to compensate for the reduced service without violating the terms of the SLA. Moreover, it is interesting to note that the authors of [39] and [23] also provided proof of concept by developing and evaluating prototypes of their solutions.

## VI. RELATED WORK

In the recent few years, systematic literature studies have received substantial popularity in various research areas. One particular example is the research area of software engineering where these studies are frequently conducted to identify various trends and gaps in the research as well as to structure the research map of the area [10], [11]. In this paper, we conduct a systematic literature study on definition and modeling of SLAs for cloud services in IoT. This topic overlaps with the broad research areas of software engineering, computer science and computer engineering. Also, the research in the general area of SLAs for cloud services in IoT is largely spread, which is indicated by the large body of work on management of SLAs in the context of cloud computing and IoT. For instance, the study in [9] identifies 328 primary studies on management of SLAs for cloud services in IoT. While focusing in this paper on the definition and modeling of SLAs for cloud services in IoT, we identify that this specific research area is also widely dispersed. This is indicated by the 59 of originally identified publications as shown in Fig. 2 and also 44 studies discussed in Section IV.

There are a few systematic literature studies and surveys of the state of the art that address SLAs in cloud computing and IoT in general. For instance, Akpan and Vadhanam [61] conduct a survey on quality-of-service management in cloud computing. Similarly, Mary and Jayapriya [62] perform a survey on resource management techniques to ensure QoS in cloud computing. Another similar survey is conducted by Firdhous *et al.* [63] to identify various approaches and methods to support QoS in cloud computing. Faniyi and Bahsoon [5] carry out a survey while focusing on allocation of resources during SLA lifecycle. Wazir *et al.* [64] present a survey of various cloud service models. Kyriazis [65] performs a state-of-the-art review of the lifecycle management of SLAs in cloud computing. In [66], a systematic mapping study on QoS approaches in cloud computing is presented. One of the main outcomes of the study refers to the lack of evidence, tools and metrics for QoS in cloud services as well as a lack of solutions to appropriately support and manage QoS according to the agreed SLAs. However, these studies and surveys do not conduct systematic literature study of definition and modeling of SLAs for cloud computing and IoT, which is the main focus of the study presented in this paper.

Mubeen *et al.* [9] conduct a systematic mapping study on management of SLAs for cloud computing and industrial IoT. This study classifies the identified relevant publications into seven different categories covering various aspects of SLA lifecycle management, including management, definition, modeling, negotiation, monitoring, violation and trustworthiness, and evolution of SLAs. Although the work in [9] constructs a map of the research on definition and modeling of SLAs, it does not conduct a survey or provide a review of the relevant publications on the definition and modeling of SLAs for cloud services in IoT. On the other hand, we leverage the study in [9] to perform a comprehensive review and discuss sub-categorization of the definition and modeling aspects of SLAs for cloud services in IoT, which are crucial in establishing SLAs between service providers and consumers.

## VII. THREATS TO VALIDITY OF THE RESEARCH RESULTS

The main threats to validity of this study are possible bias when selecting the studies to be included and inconsistency at the stages of data extraction and following classification of the articles. To ensure that the process of searching for studies to be considered and identifying the relevant ones was unbiased, discussions were undertaken to define the goal of the study, inclusion and exclusion criteria, and search strategy. After these discussions, all authors acquired a common understanding of the search and data extraction strategies.

To reduce the bias when selecting the original set of articles to be considered, we selected the search strings including possible abbreviations and related terms, searched in the most widely used databases. However, there is still a risk of missing some relevant publications in the cases when software engineering keywords are not standardized or clearly defined.

Next, to ensure the unbiased selection and reduce the risk of excluding relevant publications, a multi-step selection process was adopted. Titles and abstracts of all publications were screened to be cross-checked with the inclusion and exclusion criteria; papers marked as *Not Clear* after this step went through a separate round of full-text skimming.

At the stage of data extraction, to ensure its correctness and avoid bias is paper classification, we defined a questionnaire that was filled in for every paper. The questions and possible answers for multiple-choice questions were iterated among the authors to obtain a consistent view. Moreover, for each paper two authors filled in a questionnaire and only after the authors agreed, the answers were fed into the spreadsheet with collected data.

However, even given all the measures described above, there are several considerations that can potentially threat the completeness of the presented results:

- Fist, this study includes only the papers written in English, which means that it may be possible to miss relevant publications written in other languages.
- Also, we included only peer-reviewed publications and sorted out other scientific studies, book chapters, books and short papers as they potentially could provide not reliable information for this study.
- Next, the search was performed using electronic databases and thus we could have missed relevant articles that are for some reason available in paper format only.
- The presented results are valid only in the context of computer science and software engineering and do not cover publications from other fields, e.g., electronics, mechanical engineering, medical sciences, physics and others.
- The search string was used to search keywords, titles and abstracts. It is possible that the search string failed to identify some relevant papers as they used other keywords or the authors of these papers failed to reveal the true content of the papers in the title and abstract.
- In this study we classified the papers according to the area of their contribution, evaluated the maturity levels, extracted the data regarding application domains, tool support, etc. Despite the agreement among the evaluators on the definitions of the groups and rounds of discussions, some papers were still difficult to categorize due to thin boundaries between some classification categories and also due to the way the information was presented in the papers.
- After the study selection process, the relevant publications were selected to be further analyzed. We believe that this pool of papers is representative for the aim of this study and thus, we did not apply any snowballing or backward search in the references of the included publications.

## VIII. CONCLUSION

With cloud computing and IoT gaining more and more attention and being applied in various types of businesses and even industries, SLAs play a crucial role to ensure required levels of service to the service consumer. Thus, the main objective of this work is to study the previous contributions in the area of definition and modeling of SLAs for cloud services in IoT, evaluate their maturity level, find commonalities and research gaps. For this purpose, we conducted a comprehensive systematic literature study and identified 59 studies covering a broad spectrum of various aspects of SLA definition and modeling, out of which 44 were selected for the final evaluation after the detailed full-text reviewing. These publications vary in the type of contribution and maturity level, specific angles of SLA definition and modeling, application domain, but also have a lot of commonalities. We grouped the studies into five main categories according to the main focus of their contribution: ontology (15%), languages (18%), frameworks and methodologies (22%), templates (29%), and matching of services and consumer needs (16%). After that, each contribution was evaluated in terms of how formal it is, its maturity level, application domain, and possible tool support. The results show that in general the maturity level of the previous studies on the definition and modeling of SLAs for cloud services in IoT is low and there is space for additional research. Moreover, only few publications addresses specific application domains and thus more concrete proposals are needed to make it easier to apply the contributions on domain-specific applications in real scenarios. Similarly, even though the study revealed that the contributions within ontology and language categories are often supported by tools, more tools could be provided together with SLA definition methodologies and concrete templates. Finally, with the currently increasing trend towards Industry 4.0 and re-configurable services on-demand, more attention needs to be paid to dynamic SLAs, which were addressed only in three relevant studies.

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