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Management of Service Level Agreements for Cloud Services in IoT: A Systematic Mapping Study

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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. Therefore, ensuring quality of service (QoS) through service-level agreements (SLAs) for such cloud-based services is crucial for both the service providers and service consumers. As SLAs are critical for cloud deployments and wider adoption of cloud services, the management of SLAs in cloud and IoT has thus become an important and essential aspect. This paper investigates the existing research on the management of SLAs in IoT applications that are based on cloud services. For this purpose, a systematic mapping study (a well-defined method) is conducted to identify the published research results that are relevant to SLAs. This paper identifies 328 primary studies and categorizes them into seven main technical classifications: SLA management, SLA definition, SLA modeling, SLA negotiation, SLA monitoring, SLA violation and trustworthiness, and SLA evolution. This paper also summarizes the research types, research contributions, and demographic information in these studies. The evaluation of the results shows that most of the approaches for managing SLAs are applied in academic or controlled experiments with limited industrial settings rather than in real industrial environments. Many studies focus on proposal models and methods to manage SLAs, and there is a lack of focus on the evolution perspective and a lack of adequate tool support to facilitate practitioners in their SLA management activities. Moreover, the scarce number of studies focusing on concrete metrics for qualitative or quantitative assessment of QoS in SLAs urges the need for in-depth research on metrics definition and measurements for SLAs.

INDEX TERMS Service-level agreements, SLAs, Internet of Things, IoT, industrial IoT, IIoT, cloud computing, systematic mapping study.

I. INTRODUCTION

Cloud Computing [1] provides huge virtualized computing resources as on-demand services to users, which makes it very attractive for many industrial application domains. Therefore, using cloud computing will change the way businesses and users interact with IT resources. Furthermore, the Internet of Things (IoT) [2], [3] adds another dimension, on top of computing resources, by including everything, i.e., also the physical devices. Optimization of operations at different levels can be achieved through collecting and

analyzing data from physical and virtual world. As a result, combining cloud computing and IoT technologies can provide services to consumers and businesses, allowing organizations to become more agile and flexible in pursuing new revenue streams and new business models. These technologies provide major benefits in terms of using IT and business agility allowing a huge competitive advantage for industrial organizations. However, building new services in the cloud or designing cloud-based IoT solutions into existing business context in general is a complex decision process,

involving many factors and concerns. One major problem is concerned with 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. As a result, the quality of service, integrated in the Service Level Agreement (SLA) [4], is an important issue for both service providers and service consumers who require efficient SLA management from the complete SLA lifecycle perspective.

In this paper we consider the SLA lifecycle meta-model that is discussed in the European Commission report on recent European and national projects covering cloud computing SLAs [4]. The SLA lifecycle, depicted in Figure 1, consists of six main phases that include service use, service modeling, SLA template definition, SLA management, SLA enforcement and SLA conclusion. The phases are numbered from 1 (first phase) to 6 (last phase) in Figure 1. The first phase handles the information that affects the cloud service usage by the service consumer. The second phase deals with the modeling of the service, relationship and dependencies within the service components, and information regarding the service provision. In the third phase, SLA templates are created and other related information is captured. The fourth phase deals with the management of SLA covering various aspects such as SLA definition, SLA modeling, SLA negotiation (including SLA re-negotiation after the service provisioning in cloud), SLA monitoring, SLA evolution and SLA violation and trustworthiness. The purpose of the fifth phase is to enforce the SLA. The sixth phase handles the termination of the SLA, which can happen for various reasons such as SLA violation and/or expiry of the service period.

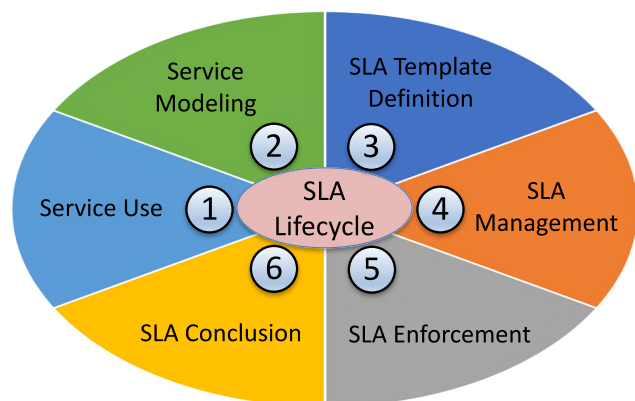


FIGURE 1. SLA lifecycle.

There exists a large body of research on IoT, cloud computing and their application in industrial systems, e.g., [5]–[17]. The research community has developed several techniques and frameworks to address various phases in the SLA lifecycle; however, the management of SLAs has received less attention. According to Papadopoulos *et al.* [18] the management of SLAs for cloud services in IoT is still a very young area of research. Hence, there is a need to construct a structured map of the research area and perform a deeper analysis to better understand which aspects of SLA management for

cloud services in IoT are mature and which aspects need more attention.

A. PAPER CONTRIBUTIONS

The main goal of this paper is to conduct a detailed investigation of the existing research on the management of SLAs in IoT applications that are based on cloud services. For this purpose, we construct a structured map of the available research literature (focusing on the above-mentioned goal) by conducting a systematic mapping study. We classify the relevant studies in relation to various aspects of SLA management. Moreover, we identify the distribution and trends of publication in the research area according to three classifications: (i) technical contributions that correspond to various aspects of SLA management for cloud services in IoT, (ii) research type and (iii) research contributions. Within the context of these classifications, we also identify the gaps in the existing research that need attention by the research community. In addition, we investigate the impacts on the state of the practice and future research directions.

B. PAPER LAYOUT

The rest of the paper is organized as follows. Section II discusses the process followed in this systematic mapping study. Section III discusses the related work. Section IV presents various classifications that are used in this study. Section V analyzes the collected data and presents the evaluation results. Section VI performs statistical analysis to evaluate the level of agreement among the researchers collecting data in this study. Section VII sheds light on threats to validity of the study. Finally, Section VIII concludes the paper and discusses the future work.

II. THE SYSTEMATICS MAPPING STUDY

The systematic mapping study is a structured method to provide an overview of a research area [19], [20]. This type of study aims at identifying published research results that are relevant to the research area. Further, the study categorizes relevant published results according to a defined classification. This method has been recommended mostly when little relevant evidence is found during the initial study of the domain, or if the topic to be investigated is very broad [21]. In this paper we conduct a systematic mapping study following the guidelines that are discussed in [19] and [20]. The work flow of the systematic mapping study used in this paper is depicted in Fig. 2.

A. SPECIFICATION OF RESEARCH QUESTIONS

The first step in the systematic mapping study is to define concrete research questions. The answers to these questions provide an overview of the existing studies including the number of publications, publication venues and distribution of publications over the years in the research area. We formulate the following Research Questions (RQs) focusing on the research area of “SLA management in IoT applications that are based on cloud services.”

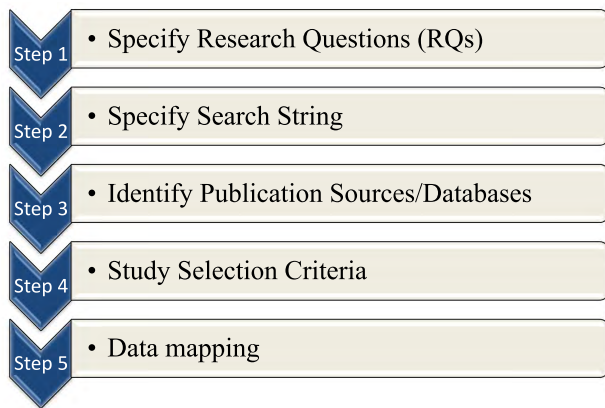


FIGURE 2. Work flow of the systematic mapping study.

RQ-1: What is the number of publications per year in the research area?

RQ-2: What are the publication trends in the research area?

RQ-3: Which main venues include publications in the research area?

RQ-4: Which main research topics have been investigated in the research area?

A detailed discussion on the research topics will be provided in Section IV-A.

RQ-5: What is the number of publications per year on the main research topics in the research area?

RQ-6: Which main types of research have been employed in the research area?

A detailed discussion on the types of research will be provided in Section IV-B.

RQ-7: Which main types of research contributions have been provided in the research area?

A detailed discussion on the types of research contributions will be provided in Section IV-C.

RQ-8: Where are the gaps in the research area with respect to the main research topics, research types and research contributions?

B. SPECIFICATION OF SEARCH STRING

After defining the research questions, the next step in the systematic mapping study is to specify the search string that is used to search relevant publications in known databases (discussed in the following subsection). In crux, the search string is based on the keywords and their alternative words that are in line with the main research goal of the paper (discussed in Section I). We use the Boolean operators OR and AND to join the keywords and their synonyms in the search string. The following string is used to search relevant publications in the known data bases:

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("service level agreement" OR sla)
AND
("internet of things" OR iot
OR "industrial internet of things"
OR iiot OR "cloud computing")
  
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In order to not miss any relevant publication for the study, we include the terms “industrial internet of things” and “iiot” as part of the search string. Note that the term “cloud computing” is included in the search string together with the keyword IoT and its synonyms. This is because IoT extends the cloud computing concept beyond computing and communication by taking physical devices into account [2], [3].

C. IDENTIFICATION OF PUBLICATION SOURCES/DATABASES

The next step in the systematic mapping study is to identify the most common scientific databases (sources of publications) in the research area. We identify the following online databases.

- 1) IEEE Xplore digital library¹
- 2) Science Direct²
- 3) Web of Science³
- 4) Scopus⁴
- 5) ACM Digital Library⁵

After identifying the databases, we use the search string (presented in Section II-B) to find available publications in the research area. We perform an open-ended search with respect to the year of publication, i.e., we search all publications conforming to the search sting that have been published in the databases until the end of 2016. On the other hand, we restrict the search with respect to the type of publications by including journal, conference and workshop papers as well as peer-reviewed book chapters. Abstracts and the publications that are not peer reviewed are excluded from the search. The Endnote tool⁶ is used to record the search results.

D. STUDY SELECTION CRITERIA

The search results in the previous step provide a pool of 3269 research publications. These publications indicate the current body of knowledge in the area of SLAs in IoT applications based on cloud services. However, the main goal of this systematic mapping study is focused on the “management” of SLAs in IoT applications based on cloud services. Hence, the collected pool of research publications should be filtered accordingly. For this purpose we provide a study selection criteria depicted in Fig. 3.

According to the criteria, in the first step, any duplicate publications should be removed from the pool. The collected pool of publications may contain duplicate publications mainly because several conferences in the research area are hosted by more than one database. For example, “the International Conference on Utility and Cloud Computing”⁷ is hosted by both IEEE Xplore digital library and ACM

¹<http://ieeexplore.ieee.org/Xplore/home.jsp>

²<http://www.sciencedirect.com/>

³<http://webofknowledge.com/>

⁴<https://www.scopus.com/>

⁵<http://dl.acm.org/>

⁶<http://endnote.com/>

⁷<http://ucc-conference.org/>

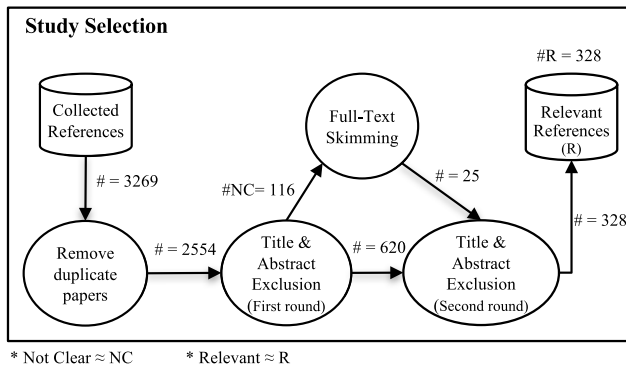


FIGURE 3. Study selection process in the systematic mapping study.

Digital Library. In this step we identify 715 duplicate publications. After removing the duplicates, the pool reduces to 2554 publications.

Next, the remaining pool of publications (2554) is divided into three classes based on reviewing their titles and abstracts. The three classes are listed below. This step is identified by the oval with text “Title & Abstract Exclusion (First round)” in Fig. 3.

- Relevant (R) – If the title and abstract of a publication clearly indicate that it addresses the main goal of this systematic mapping study, the publication is categorized as R.
- Not Relevant (NR) – If the title and abstract of a publication clearly indicate that it does not address the main goal of this systematic mapping study, the publication is categorized as NR.
- Not Clear (NC) – A publication is categorized as NC if it cannot be classified as relevant or non-relevant.

This step results in 620 R and 1818 NR publications. Whereas, 116 publications could not be categorized as R or NR based on reading only the titles and abstracts. Hence, these 116 publications are categorized as NC. In the next step, we perform the full-text skimming of the collected set of NC publications. This step results in 25 R and 91 NR publications. Hence, the total number of R publications after these steps is equal to 645 (i.e., 620+25).

While performing the first exclusion step, we find out that many R publications are heavily focused on the scheduling and resource management, whereas the management of SLAs in IoT applications is slightly discussed. In order to filter out such publications from the ones that are focused on the main goal of this systematic mapping study, we perform a second exclusion step as shown in Fig. 3. The second exclusion step also exercises the inclusion/exclusion decision based on the titles and abstracts. In this step, we classify each publication in the remaining pool of 645 publications as R or NR. If a publication cannot be categorized based on its title and abstract then the full-text skimming is carried out. The second exclusion step results in 328 R publications as shown in Fig. 3.

E. DATA MAPPING

In this step, the collected data (i.e., the pool of 328 R publications) is classified independently in three classes. The classification is based on titles and abstracts of the publications. If a publication cannot be classified based on its title and abstract then the full-text skimming is performed. Each class is divided into several categories.

The first class is based on technical classification, which refers to the management of SLA’s in IoT applications that are based on cloud services. Note that the term “management” in the context of SLAs is a broad term and contains many aspects [22]. The main goal of this systematic mapping study coincides with only few aspects of SLA management including SLA definition, SLA modeling, SLA negotiation, SLA monitoring, SLA evolution and SLA violation and trustworthiness. The details about these terms will be discussed in Section IV-A. Note that any R publication can belong to more than one category of the technical classification.

The second class is based on the research approach used in the publications. In this study, we are interested in the following research approaches: solution proposal, validation research, conceptual proposal, evaluation research and experience papers. The details about this classification will be discussed in Section IV-B.

The third class is based on the type of research contribution provided in the publications. Examples of research contributions include method (technique/approach), model (framework), metric, tools and others. The complete explanation about each category in this class will be discussed in Section IV-C.

III. RELATED WORK

A few surveys, systematic reviews and systematic mapping studies relevant to the SLAs in cloud computing and IoT have been conducted. For example, the study [23] conducts a survey on Quality of Service (QoS) management techniques that are used for allocating resources to the applications to guarantee services based on performance, availability and reliability. Similar studies are done in [24] and [25]. The study in [24] surveys the techniques and frameworks that handle resource management to ensure QoS in cloud computing; whereas the study in [25] surveys the mechanisms and methods used for measuring and ensuring QoS in cloud computing.

A systematic mapping study is conducted in [26] on the topic of QoS approaches in cloud computing. The study identifies the challenges and gaps that require future research explorations, e.g., tools, metrics and evaluation research are needed in order to provide cloud services with trustworthy QoS. The study looks into different focus areas with respect to (i) Software-as-a-service (SaaS) addressing QoS application requirements, application performance and monitoring management, and application scalability; (ii) Infrastructure-as-a-service (IaaS), addressing resource management, resource performance and

monitoring management; (iii) Platform-as-a-service (PaaS). In addition, the study investigates QoS aspects related to (i) Cloud service provider (CSP) perspective, with respect to SLA support (i.e., methods and models that provide SLA support to service providers), SLA support profits (i.e., methods to increase revenue for service providers), and SLA support resources (i.e., resource assignment to minimize the cost and maximize the profit in the context of supporting SLAs); and (ii) Cloud service consumer (CSC) perspective, with respect to metrics models in order to determine the resources needed for allocation.

The study in [27] focuses on the resource allocation phase of the SLA life cycle. Based on the survey, the majority of research considers a minimum number of SLA parameters where the most studied parameters are performance, memory and CPU cycle. The study in [28] reviews the various models proposed for SLAs in different cloud service models, and analyzes how these models overcome the challenges related to performance, customer-level satisfaction, security, profit and SLA violation.

The study in [4] reports the research outcomes from the European and National projects, and discusses how these outcomes address the complete SLA life cycle, covering service use, service modeling, SLA template definition, SLA instantiation and management, SLA enforcement, and SLA conclusion. In addition, this report introduces a set of recommendations to support the on-going policy work on SLAs of the Cloud Select Industry Group (SIG), while identifying the research outcomes that can be exploited for the implementation of the recommendations.

These studies have surveyed the current and future challenges to QoS and SLA in cloud computing from different specific perspectives. However, a comprehensive overview of SLA management that spans the whole life cycle is missing from the state of the art and practice. In this context, this paper conducts a systematic mapping study on the available research literature on SLA management for IoT applications based on cloud services. The paper also classifies relevant studies in relation to the complete SLA life cycle.

IV. CLASSIFICATION CRITERIA

In this section we describe the identified classification criteria used in the rest of this study. Table 1 summarizes the proposed classification categories, that are described in more detail in the following.

A. TECHNICAL CLASSIFICATION

- 1) **SLA management.** With “SLA management” we here refer to the general management of SLAs that covers two or more of the following categories. The SLA management is responsible for the SLA template generation, negotiation, configuration, enforcement, maintenance, and evolution [22].
- 2) **SLA Definition.** A cloud service provider can provide services such as Infrastructure-as-a-Service (IaaS), Platform-as-a-Service (PaaS) and

TABLE 1. Summary of the proposed classification categories.

Technical classification
SLA management
SLA definition
SLA modeling
SLA negotiation
SLA monitoring
SLA violation & trustworthiness
SLA evolution
Research type classification
Solution proposal
Validation research
Conceptual (philosophical) proposal
Evaluation research
Experience paper
Research contribution classification
Method (Technique/Approach)
Model (Framework)
Metric
Tools
Others

- Software-as-a-Service (SaaS) to the consumer. Before the services can be provided to the consumer, both the provider and the consumer must agree on the metrics, level, quality, price and penalties (in the case of degraded service level or quality) regarding the services. A formal document containing all this information, which is agreed upon by both the provider and the consumer is called the SLA [29]–[31]. Various metrics that can be part of an SLAs are identified in [32]. For example, the metrics for IaaS include CPU capacity, boot time, storage, response time, just to name a few. Some examples of metrics for PaaS include deployment platforms, browsers and number of developers. Similarly, the examples of SaaS metrics include performance, availability, scalability and reliability. This category includes all the publications related to the definition of SLAs.
- 3) **SLA Modeling.** This category includes frameworks, templates, and modeling languages that have been proposed in the literature to model SLAs, see for example [33]–[36].
 - 4) **SLA Negotiation.** SLAs are formally negotiated agreements between a service provider and a customer, e.g., the quality and reliability of the service, price, execution time or average response time, etc. There may exist a gap between the expected requirements (i.e., service level) from the consumer and the level of the service that the provider can provide. If this gap does exist, then the provider and consumer negotiate to reach a mutually-agreed service level. Once the negotiation process is successful then the agreed upon

service level becomes part of the SLA. This process is called SLA negotiation [29]–[31].

It should be noted that an SLA can be non-negotiable or negotiable. A non-negotiable SLA is not subject to discussion or modification. This type of SLA is offered to the customer as take it or leave it. On the other hand, negotiable SLAs are open to negotiation before the service provisioning in the cloud. In addition, these SLAs can also be dynamically re-negotiated after the service provisioning in the cloud. Current cloud technologies offer a limited support for dynamic negotiation of SLAs between participants [37]. In this study, we group non-negotiable, negotiable and re-negotiable SLAs in one category, namely SLA negotiation.

- 5) **SLA Monitoring.** In the SLA contract, the expected level of service between the consumer and the provider is included. The QoS attributes that are generally part of an SLA (such as response time and throughput) however change constantly, and to enforce the agreement, these parameters need to be closely monitored to verify whether the offered service is meeting the QoS parameters specified in the SLA [29]–[31]. In order to monitor the QoS parameters, various techniques may be used to measure them [33], [38], [39]. This includes tools to measure, for example the network bandwidth, to check whether it follows the SLA.
- 6) **SLA Violation & Trustworthiness.** This category is related to the evaluation of whether the QoS of a service complies (meets the specified level) with an SLA or not. It also includes SLA enforcement, i.e., the management of the resources for minimizing the economic penalties derived from the possible SLA violations [40], and trustworthiness, i.e., the degree of compliance of a cloud service provider to the promised quantitative QoS parameters as defined in the SLA [41]. This category relates to different relevant problems, such as reliability, availability, dependability, security and performance.
- 7) **SLA Evolution.** This category relates to the lifecycle management of SLA, and to the adaptation of changing requirements between the different parties after the first agreement. In general, SLA lifecycle management consists of three general phases namely creation, operation and removal phases. Each phase can be further expanded to sub-phases. The SLA creation includes three sub-steps, i.e., discover service provider, SLA definition and SLA establishment [42]. Once service providers are discovered, customers have to be aware of the detailed capacity of the service providers. Therefore, the service providers describe and define their services properly and deliver the definition of their services to the customers. Then, the customers further establish the agreement(s) with one or more service providers based on the service definition through a process of SLA negotiation.

B. CLASSIFICATION BASED ON RESEARCH TYPE

This taxonomy reflects the research approaches used in the relevant publications. It serves the purpose of analyzing and understanding the maturity and weight of the state-of-the-art research. We use a reduced version of the classification scheme summarized in [43], that is a general taxonomy, independent from any specific focus area of research. In particular, we consider the following classes:

- 1) **Solution proposal.** The publications from this class propose a novel solution technique(s) for a problem and argue for its relevance. They can also propose a new significant extension to an existing technique. A proof-of-concept of the proposed technique may be offered by means of a small example, a sound argument, or by some other means.
- 2) **Validation research.** This class concentrates on investigating a proposed solution, which is novel and has not yet been implemented in practice. The publications from this class investigate the properties of a solution proposal. Investigations are carried out systematically, i.e., prototyping, simulation, experiments, mathematical systematic analysis and mathematical proof of properties.
- 3) **Conceptual (Philosophical) proposal.** The publications from this class describe a new way of looking at things by structuring a conceptual framework or taxonomy.
- 4) **Evaluation research.** The publications from this class focus on evaluating a problem or an implemented solution in practice, i.e., case studies, field studies and field experiments.
- 5) **Experience paper.** The publications from this class present personal experiences of the author(s), explaining how a research problem or a challenge is tackled in practice.

C. CLASSIFICATION BASED ON RESEARCH CONTRIBUTION

For categorizing the relevant publications based on research contribution, we use a classification similar to the one defined in [19] and [44]. In particular, the categorization is as follows:

- 1) **Method (Technique/Approach).** This class includes the publications describing how to manage SLAs for cloud-based services in IoT applications. We can include publications with methods describing general concepts but also publications with more specific and detailed working procedures.
- 2) **Model (Framework).** This class focuses on representing the information to be used to support the actual SLA and QoS. Some examples of publications in this class can be models that aim to do resource optimization, recourse management, SLA monitoring or QoS computation.
- 3) **Metric.** This class can provide new or specific measurements for certain properties in QoS. An example of a measurement in this category can be measuring

TABLE 2. Technical classification of all relevant publications collected from the systematic mapping study. Note that the references identified with blue-color bold text are common between two different categories of the technical classification.

SLA Management	SLA Definition	SLA Modeling	SLA Negotiation	SLA Monitoring	SLA Violation & Trustworthiness	SLA Evolution
[42], [45], [57], [58], [70], [71] , [83] , [84] , [96] , [97], [109], [110], [122], [123], [134], [135], [145], [146], [157], [158], [169], [170], [181], [182], [193], [194], [204], [205] , [216], [217], [228], [229] , [238], [239], [246], [247], [256], [257], [265], [266], [275], [276], [283], [284], [291], [292], [300], [301], [307], [178] , [159] , [37] .	[46] , [47], [59], [60], [72], [73], [85] , [86], [98], [99], [111], [112], [124], [125], [136], [137], [147], [148], [159] , [160], [171], [172], [183], [184], [195] , [196], [206], [207], [218], [219], [208] , [230] .	[48] , [49], [61], [32], [74], [75], [87], [88], [100], [101] , [113], [114], [126], [127], [138], [139] , [149] , [150], [161], [162], [173], [174], [185], [186], [197], [62], [208] , [209], [220], [221], [108] , [231], [230] , [121] , [248], [249] , [258], [259], [267] , [268], [106] , [46] , [260] , [229] , [293] , [294] .	[50], [40] , [62], [63], [76], [77] , [89], [90], [102], [103], [115], [116], [128], [129], [40] , [140], [151] , [152], [163], [164], [175] , [176], [187], [188], [198], [199], [210], [211], [222], [223], [232], [233], [240], [241], [250], [251], [260] , [258], [269], [270], [277], [278], [285], [286], [295], [296], [302], [303], [308], [309], [314], [315], [320], [321], [326], [327], [332], [333], [37] , [338], [343], [344], [348], [349], [293] , [294] , [354], [353], [353], [48] , [85] , [139] , [205] , [195] , [249] , [357], [358], [359], [360].	[51], [52], [64], [65], [78], [79], [91], [92], [104], [105], [117], [118], [130], [131], [141], [142], [153], [154], [165], [166], [177], [178] , [189], [190], [200] , [201], [212], [213], [224], [225], [234], [235], [242], [243], [252], [253], [261], [262], [271], [272], [279], [280], [287], [288], [288], [297], [38], [304], [310] , [311], [316], [317], [322], [323], [328], [329], [334], [335] , [339], [340], [345] , [84] , [96] , [77] , [119] , [68] , [151] , [175] , [149] .	[53], [54], [66], [67], [80], [81], [41], [93], [106] , [107], [119] , [120], [132], [133], [143], [144], [155], [156], [167], [168], [179], [180], [191], [192], [202], [203], [214], [215], [226], [227], [236], [237], [244], [245], [254], [255], [263], [264], [273], [274], [281], [282], [289], [290], [298], [299], [305], [306], [312], [313], [318], [319], [324], [325], [330], [331], [336], [337], [341], [342], [346], [347], [350], [351], [352], [353], [355], [71] , [40] , [356] , [83] , [101] , [200] , [310] , [335] , [345] , [267] .	[55], [56], [68] , [69], [27], [82], [94], [95], [42] , [108] , [121] .

the time load that service provider acknowledges the receipt of reported problem.

- 4) **Tools.** This class refers to any kind of tool or tool support for the attributes included in the SLAs (like Linked USDL, tools for measuring performance, etc.).
- 5) **Others.** This class includes the remaining publications that include issues not covered by the other classes above.

V. RESULTS AND EVALUATION

This section analyzes the collected data and discusses the evaluation results.

A. IDENTIFIED RELEVANT PUBLICATIONS

The study selection process, discussed in Section II, has resulted in a pool of 328 relevant publications. These publications are referenced in Table 2. It should be noted that the

TABLE 3. Top seven publication venues in the research area.

Rank	Publication channel	Publication venue	Number of publications	Percentage
1	Conference	International Conference on Cloud Computing and Service Science	19	8.80
2	Journal	Future Generation Computer Systems	16	7.41
3	Conference	International Conference on Services Computing	9	4.17
4	Conference	International Conference on Cloud Computing	6	2.78
5	Conference	International Conference on Utility and Cloud Computing	5	2.31
6	Conference	International Conference on Cloud Computing Technology and Science	5	2.31
7	Conference	International Symposium on Cluster, Cloud, and Grid Computing	4	1.85

detailed analysis of the categories of the technical classification in this table will be discussed in Section V-D. The pool of publications represents the existing body of research in the area of management of SLAs for IoT applications based on cloud services.

B. IDENTIFIED RELEVANT VENUES

This subsection provides the map of the collected pool of relevant publications with respect to their venues of publication. Moreover, the most frequent venues of these publications are identified.

We note that the collected pool of relevant publications have been published in 216 different conferences and journals. Table 3 depicts the top seven venues, out of 216, in which approximately 29.6% of the relevant publications have been published. The share of the top seven venues in the pool of relevant publications is as follows. The International Conference on Cloud Computing and Service Science⁸ has published 8.80% of the relevant publications. Therefore, this conference can be considered as the undisputed main conference in the research area. The second rank, in this context, belongs to the Elsevier journal on Future Generation Computer Systems.⁹ The journal has published 7.41% of the relevant publications. Hence, the journal can be regarded as the most frequent journal for publishing research results in the research area. The remaining five venues in Table 3 are conferences that have published around 4% down to 2% of the relevant publications. The rest of the venues, that are not listed in the table, have published three or less relevant publications. This means that 264 relevant publications, approximately 70.4% of the pool, are scattered in 209 different conferences and journals. Apart from the top seven publication venues, the wide-spread distribution of the relevant publications over the rest of the venues shows that the research community has not yet achieved focused publication venues. This indicates a need for more focused publication venues in the research area such as workshops, conferences and journals.

These results can provide guidance to new researchers in searching relevant publications and in identifying the most

relevant publication venues for their results in this research area.

C. DISTRIBUTION OF ALL RELEVANT PUBLICATIONS

This subsection investigates the current publication trends in the research area by performing an analysis of the collected pool of relevant publications. Fig. 4 depicts a graph between the number of relevant publications that have been published in the known databases over the years. It is interesting to note that the first research results in this area were published in 2009. This indicates that the research area is fairly new. The trend, identified by the black line in Fig. 4, shows an increase in the attention received by the research topic of this study in the recent years. This is indicated by more than eleven-fold increase in the number of relevant publications from 6 in 2009 to 69 in 2015.

The graph in Fig. 4 shows that the number of relevant publications in 2016 is significantly lower than 2015. The reason is that the search in the databases is performed in the beginning of 2017. This means that the search results include the publications that have been published until the end of 2016. However, many conferences and journals take a considerable amount of time in processing the proceedings and issues respectively. For example, consider the International Conference on Utility and Cloud Computing,¹⁰ which is the fifth most frequent publication venue in the research area as shown in Table 3. The recent instance of this conference took place from 6-9 December, 2016. Whereas, the proceedings were published in IEEE Xplore digital library on 20th March, 2017. Although the conference took place in 2016, the proceedings did not show up in our search. Considering this aspect, we believe, the exact number of relevant publications in 2016 will be similar or higher than 2015.

D. DISTRIBUTION OF RELEVANT PUBLICATIONS WITH RESPECT TO THE TECHNICAL CONTRIBUTIONS

This subsection investigates the current publication trends with respect to the technical contributions included in the relevant publications. We have discussed six technical categories in Section IV-A including the SLA definition, SLA modeling, SLA negotiation, SLA monitoring, SLA evolution

⁸<http://closer.scitevents.org/Websites.aspx>

⁹<https://www.journals.elsevier.com/future-generation-computer-systems>

¹⁰<http://computing.derby.ac.uk/ucc2016/>

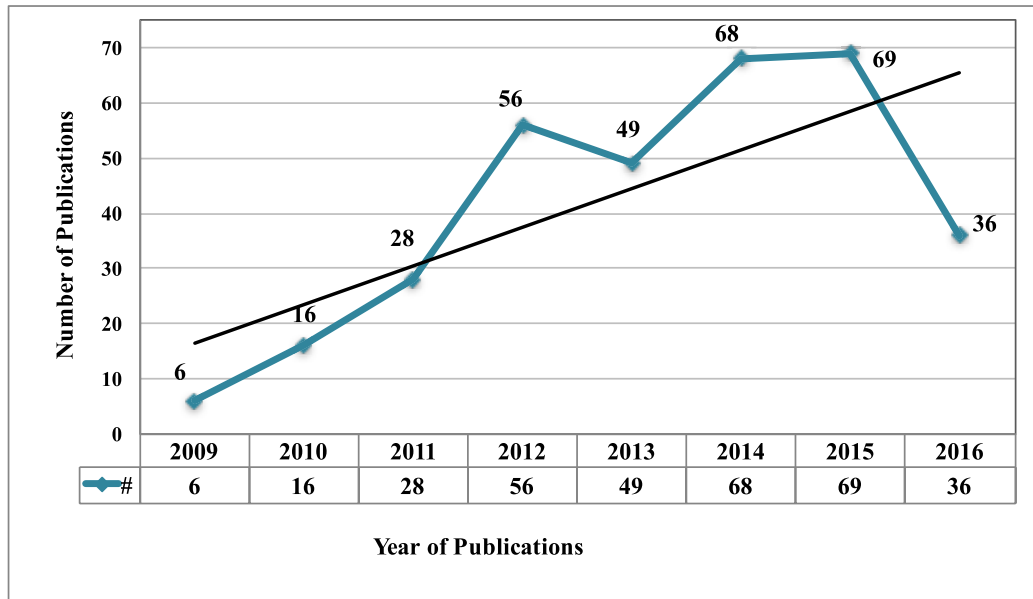


FIGURE 4. Distribution of relevant research publications on the management of SLAs in IoT applications based on cloud services according to publication year. The black line represents the linear trend of the obtained data.

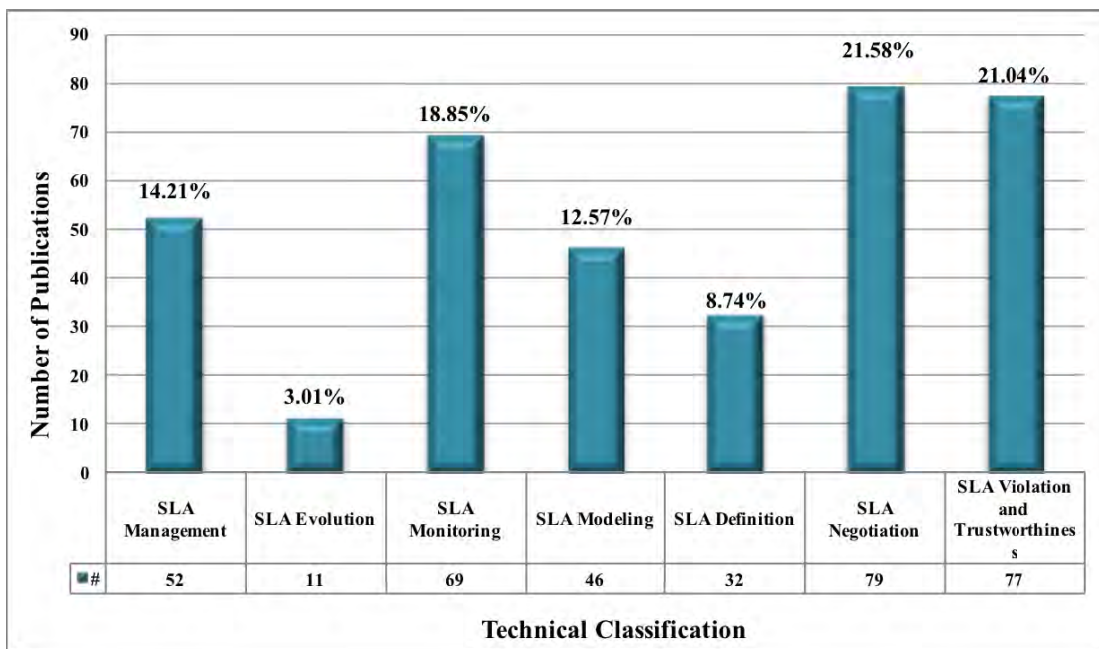


FIGURE 5. Distribution of relevant publications according to the technical classification.

and SLA violation and trustworthiness. The six categories actually represent various aspects of SLA management. All relevant publications are classified according to these technical categories in Table 2. During the categorization process we identified that some publications do not address any specific technical category, rather they address the SLA management in general. Hence, we include one general category as “SLA management” in Table 2. It should be noted that some publications belong to more than one technical category, e.g., publication [85] addresses both SLA definition

and SLA negotiation. The publications that address more than one technical category are identified with the blue bold text in Table 2.

Fig. 5 depicts a bar graph indicating the number of publications as well as the percentage of the pool of relevant publications targeting each category in the technical classification. It is obvious from the figure that SLA negotiation and SLA violation and trustworthiness are the most frequently addressed technical categories in the research area. These two contribution have been addressed in 21.58% and 21.04%

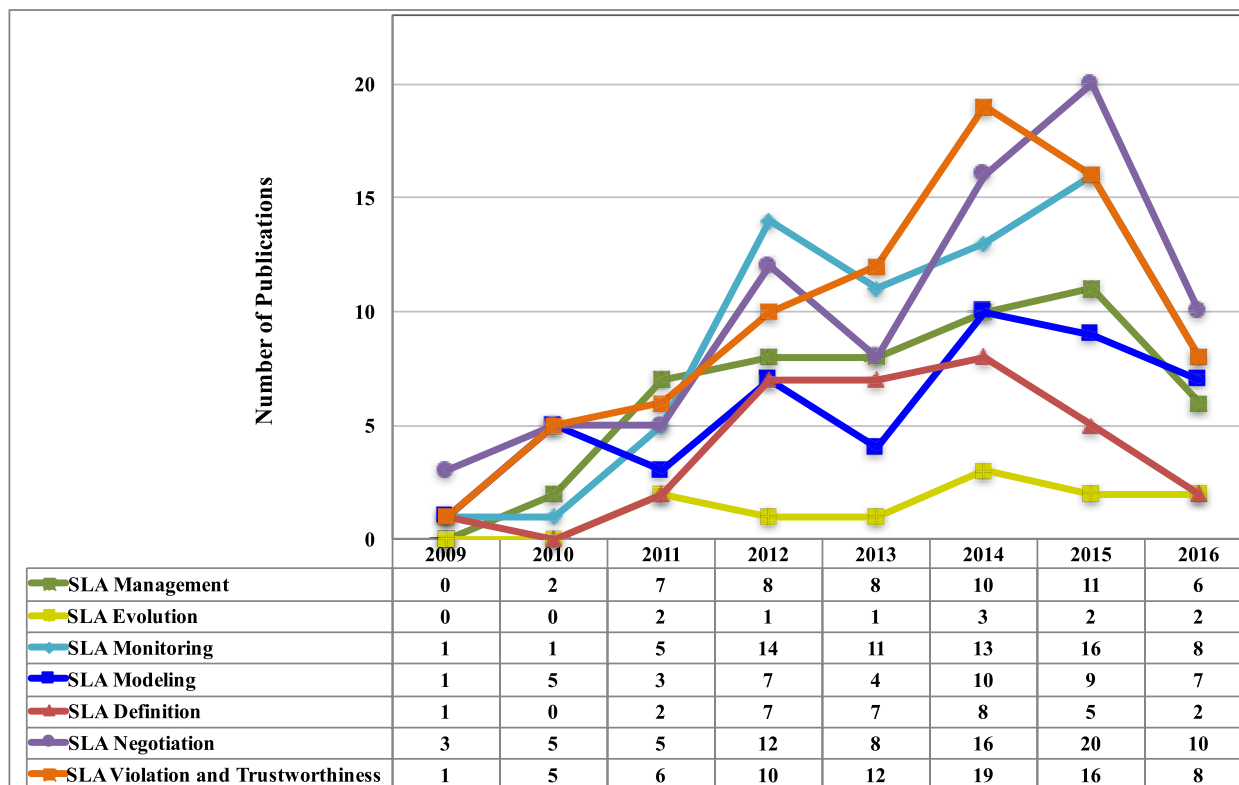


FIGURE 6. Distribution of relevant publications in each technical category with respect to the publication year.

of all relevant publications respectively. On the other hand, SLA evolution and SLA definition are the least addressed contributions in the research area. These two contributions have been addressed by only 3.01% and 8.74% of all relevant publications respectively. The smaller bars in Fig. 5 indicate that the definition, modeling and evolution of SLAs needs more attention by the research community.

The number of publications addressing each technical category is plotted against the publication years in Fig. 6. The figure shows that the first research results in the technical categories of SLA monitoring, SLA modeling, SLA definition, SLA negotiation and SLA violation and trustworthiness were published in 2009. Whereas, the first research results in the categories of SLA management (in general) and SLA evolution were published in 2010 and 2011 respectively. Fig. 6 shows that there is an increasing trend in the number of publications over the years in all categories of the technical classification. Fig. 6 also shows that SLA monitoring, SLA negotiation and SLA violation and trustworthiness have received most attention by the research community. Note that the reasoning and explanation about the lower number of publications in 2016 compared to 2015 discussed in Section V-C also applies to this subsection.

E. DISTRIBUTION OF RELEVANT PUBLICATIONS WITH RESPECT TO THE RESEARCH TYPE

Fig. 7 depicts a bar graph indicating the number of publications as well as the percentage of the pool of relevant

publications targeting each category in the research type classification (discussed in Section IV-B). It can be seen from the figure that an overwhelming majority of the existing research has adopted the solution proposal research type, constituting 81% of all relevant publications. Only 9% of the relevant publications have employed evaluation research. Whereas, 3%, 2% and 4% of the relevant publications employ validation research, experience papers and conceptual proposals respectively. The results corresponding to the evaluation research show that only 9% of the research results in the area have been implemented and evaluated in practice. Note that the results achieved through the evaluation research have higher chances to find their way to the industry [19]. Fig. 7 shows that a large majority of research results in the area appear to be not yet mature to be adopted by the industry.

F. DISTRIBUTION OF RELEVANT PUBLICATIONS WITH RESPECT TO THE RESEARCH CONTRIBUTION

In this subsection we explore the distribution of all relevant publication with respect to the research contribution classification discussed in Section IV-C. Fig. 8 depicts a bar graph indicating the number of publications as well as the percentage of the pool of relevant publications that address each category in the research contribution classification. The figure shows that the research community has focused more on providing methods/techniques and models/frameworks as research contributions because these two categories constitute 44% and 41% of all relevant publications respectively.

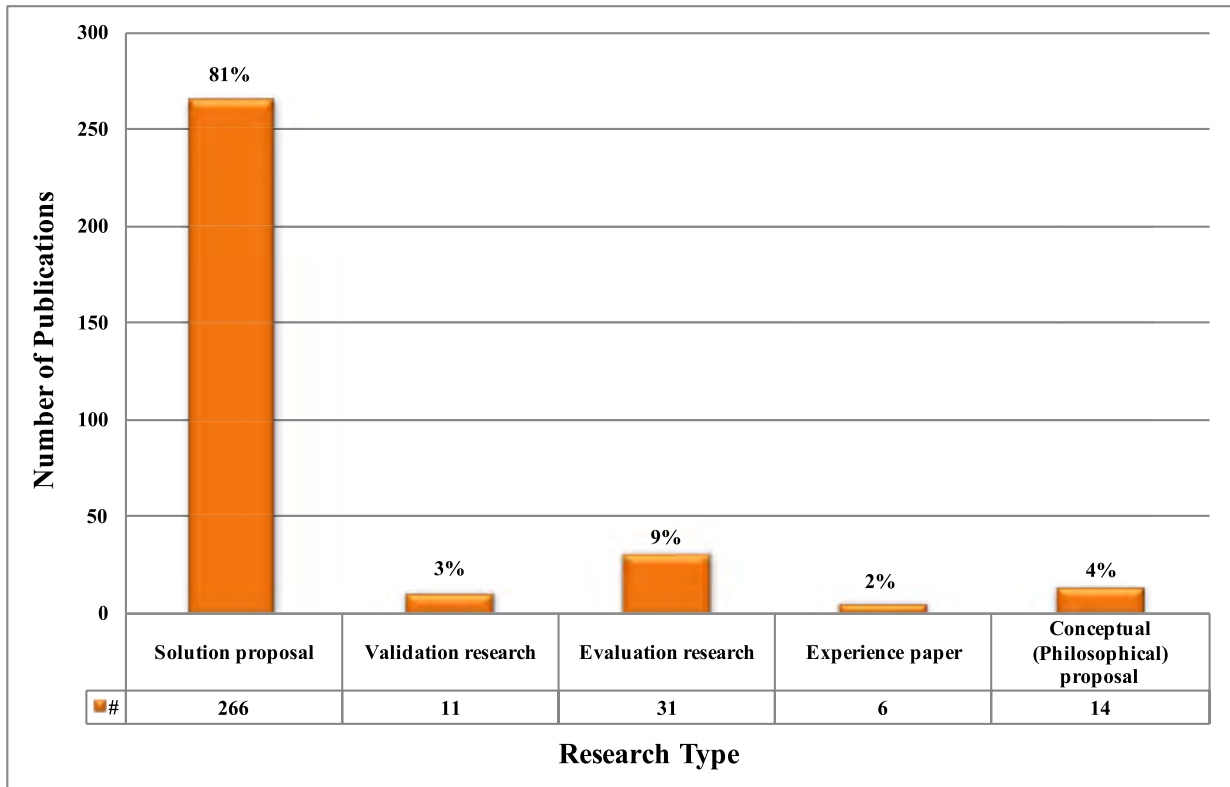


FIGURE 7. Distribution of relevant publications according to the research type classification.

On the other hand, the categories of metrics and tools have received very less attention as these categories contribute only 7% and 4% to the pool of relevant publications respectively. These results indicate that there is a lack of research regarding new solutions as metrics and tools for the management of SLAs in IoT applications that are based on cloud services.

G. RELATION AMONG THE RESEARCH TYPE, RESEARCH CONTRIBUTIONS AND TECHNICAL CONTRIBUTIONS

This subsection investigates the relationship among the three different classifications discussed in Section IV. The purpose of this investigation is to understand the main focus of the current body of research in the area as well as identify potential gaps that require immediate attention by the research community. In order to better understand the relationship among the three classifications simultaneously, we use a two-quadrant bubble plot as shown in Fig. 9. Each quadrant of the bubble plot is a two-axis scatter plot with bubbles at the intersection of any two categories belonging to different classifications. The size of the bubbles shows the number of relevant publications addressing the pair of categories intersecting each other. The left quadrant of the bubble plot illustrates the relationship between the technical contribution classification and the research type classification. Whereas, the right quadrant is plotted between the technical contribution classification and the research contribution classification.

It is obvious from the left quadrant that a large majority of the existing research has focused on solution proposals, while the rest of the categories in the research type classification have received very less attention. The largest bubble in the left quadrant has a size of 66. This bubble exists between the “solution proposal” and “SLA Negotiation” pair. This means, there are 66 relevant publications that address this pair. Note that the sum of the sizes of all bubbles in the left-most bubble column (equals to 290) in Fig. 9 is higher than the size of the left-most bar (equals to 266) in Fig. 7. The reason for the difference between the two numbers is that 24 publications (290 - 266) belonging to the solution proposal category are common in more than one category of technical classification. This means, the left-most column of bubbles in Fig. 9 contains 24 duplicates. The same reasoning applies to the rest of the bubble columns in Fig. 9.

The right quadrant in Fig. 9 shows that the majority of publications in the research area provide models/frameworks and methods/techniques as research contributions. Whereas, the metric and tool categories of the research contribution classification have not received much attention. This is evident from the gaps as well as the small size of the bubbles in the right quadrant of Fig. 9. The largest bubble in the right quadrant has a size of 43. This bubble indicates that there are 43 relevant publications that address the “method” and “SLA Violation and Trustworthiness” pair.

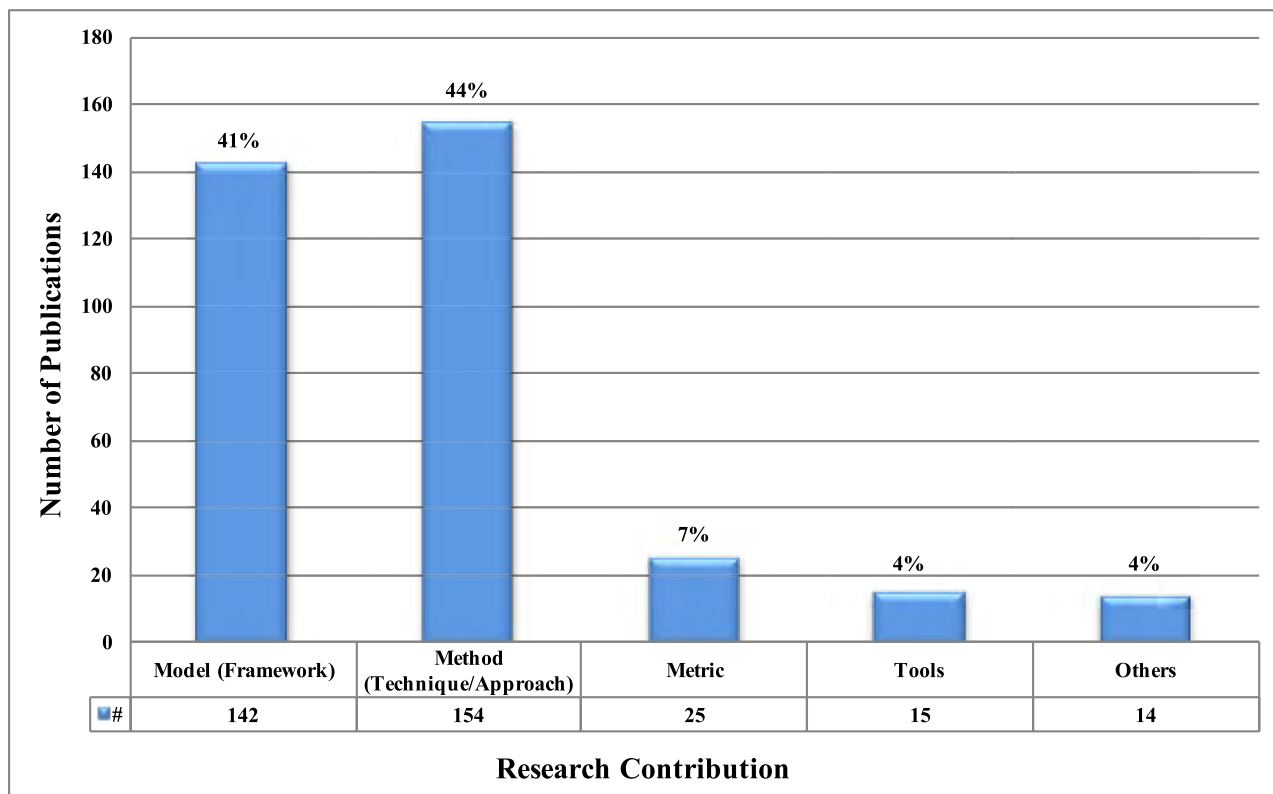


FIGURE 8. Distribution of relevant publications according to the research contribution classification.

Fig 10 shows a pie chart of the largest bubble column in the left quadrant of Fig. 9, depicting the percentage of each technical classification category in the publications that provide solution proposals. SLA negotiation and SLA violation and trustworthiness are the most focused technical categories in the solution proposals. Whereas, SLA evolution is the least addressed category in the solution proposals. Similarly, Fig 11 shows a pie chart of the largest bubble column in the right quadrant of Fig. 9. This bubble column corresponds to the method category of the research contribution classification. The results indicate that the research community has mainly addressed SLA negotiation and SLA violation and trustworthiness when providing method as a research contribution. On the other hand, SLA evolution is the least addressed technical category in the existing research when providing method as a research contribution.

H. DISCUSSION

This subsection revisits the research questions (posed in Section II-A) and answers them in relation to the evaluation results.

RQ-1: What is the number of publications per year in the research area?

The number of relevant publications per year in the research area are plotted in Fig. 4. Hence, this research question has been answered in Section V-C.

RQ-2: What are the publication trends in the research area?

The trend of relevant publications over the years in the research area is depicted in Fig. 4. Hence, this research question has been answered in Section V-C.

RQ-3: Which main venues include publications in the research area?

The main publication venues in the research area are discussed in Section V-B. The top seven publication venues are identified in Table 3.

RQ-4: Which main research topics have been investigated in the research area?

The main research topics in the research area are identified in Table 2. The number and percentage of relevant publications on the research topics are shown in Fig. 5. Table 2 can be very helpful for the researchers as well as practitioners who are interested in using, reusing or applying already developed methods, techniques and solutions in a specific category of the technical classification. For instance, if a researcher or a practitioner is interested in SLA modeling, the solutions presented in the publications listed in the third column (from the left side) of Table 2 can prove helpful.

RQ-5: What is the number of publications per year on the main research topics in the research area?

The number of relevant publications per year on the main research topics are plotted in Fig. 6. Hence, this research question has been answered in Section V-D.

RQ-6: Which main types of research have been employed in the research area?



FIGURE 9. Relationship among the categories of the research type, research contribution and technical contribution classifications in all relevant research publications.

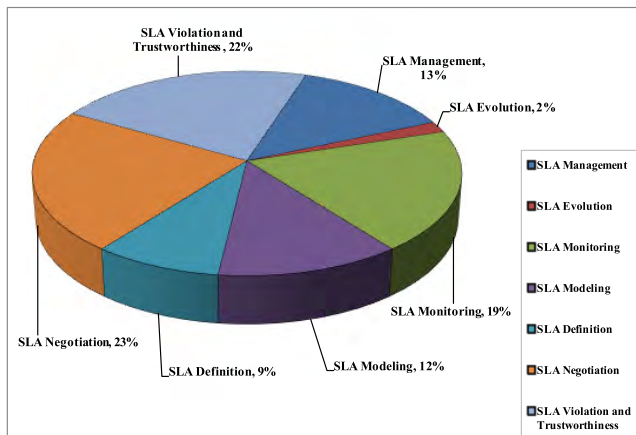


FIGURE 10. Pie chart of the most frequent research type (Solution Proposal) with respect to the technical classification in Fig 9.

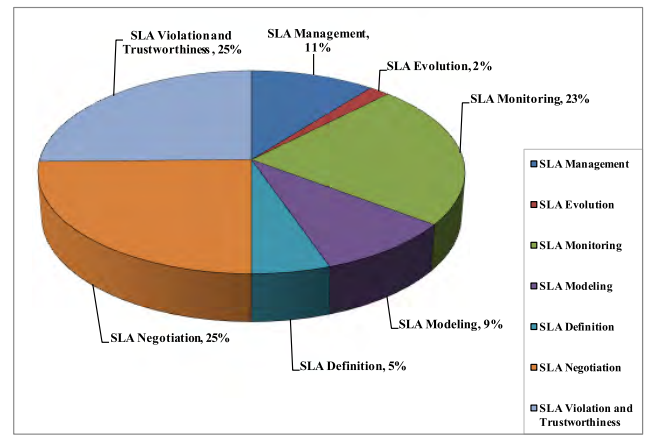


FIGURE 11. Pie chart of the most frequent research contribution (Method) with respect to the technical classification in Fig 9.

The main types of research employed in this area are discussed in Section V-E.

RQ-7: Which main types of research contributions have been provided in the research area?

The main types of research contributions provided in this area are discussed in Section V-F.

RQ-8: Where are the gaps in the research area with respect to the main research topics, research types and research contributions?

The relationship among the main research topics, research types and research contributions are discussed with a bubble chart in Fig. 9 and with a couple of pie charts in Fig. 10 and Fig. 11. This question has been answered in Section V-G.

VI. FLEISS' KAPPA STATISTICAL ANALYSIS

In this section we perform statistical analysis to evaluate the level of agreement among the researchers collecting data in this systematic mapping study. Cohen [361] introduced a statistical method to measure the degree of agreement between two raters who rate a sample of a subject. He introduced the notion of Kappa in which the hypothetical agreement by chance is also taken into account. Later, the limitation of two-raters was eliminated by Fleiss [362], who generalized the method for multi-raters. In this work we use the Fleiss' Kappa analysis to show the degree of agreement when we decide on choosing the relevant publications.

Consider the study selection criteria that is discussed in Section II-D. In the first round of selecting relevant

publications, six raters decide about the relevance of all collected publications. Each publication is classified as one of the three categories. These categories include Relevant (R), Not Relevant (NR) and Not Clear (NC). In order to perform the Fleiss' Kappa analysis, we randomly select 98 publications out of already rated publications. Therefore, from the Fleiss method point of view, there are 98 subjects (the randomly selected publications), 6 raters (computer scientists) and 3 categories of decision as mentioned above. We apply the statistical method and calculate the overall agreement over the 98 publications as 81.7%. This means, if a randomly selected subject is rated by a randomly selected rater and then the process is repeated, there is 81.7% chance to get the same rating decision the second time. Several researchers have provided interpretations of the Kappa analysis. According to McHugh [363], the Kappa value over 90% shows an *Almost Perfect* level of agreement among the raters. Whereas, the Kappa value between 80% and 90% indicates a *Strong* level of agreement among the raters. It can be concluded, based on the Kappa statistical results, that the researchers performing this systematic mapping study have a *Strong* level of agreement in deciding relevant publications in the research area.

VII. THREATS TO VALIDITY OF THE RESEARCH RESULTS

The main threats to validity in this mapping study are bias in our selection of the studies to be included, and the classification scheme based on data extraction. To be able to identify relevant studies and ensure that the process of selection was unbiased, discussions were undertaken to define research questions, inclusion and exclusion criteria, and search strategy. After these discussions, we agreed upon the formulation of research questions, whether the search string was appropriately derived from the research questions, and whether the data to be extracted would correctly address the research questions.

Although, we tried to reduce the bias, due to our choice of search terms, there is still a risk of missing some relevant studies, especially in the cases when some software engineering keywords are not standardized and clearly defined. We dealt with this threat by making sure that all researchers participating in this study understood and agreed to the same definition of the terms that were not clear before.

To further ensure the unbiased selection of publications, we performed a multi-step selection process to minimize the risk of excluding relevant studies. All the authors were involved in the study selection process based on the inclusion/exclusion criteria. The publications collected by performing the search were reviewed with respect to their titles and abstracts. If a publication could not be judged for relevance based on its title and abstract, the full-text skimming was performed to decide about its relevance in the research area.

To ensure the reliability of inclusion decisions, we applied the Fleiss Kappa statistic to measure the agreement among all the authors. The value of the Kappa statistics is 81.7%,

which is within the range for significant agreement. Applying the Fleiss Kappa method provides us very good input for the degree of agreement on publications that should be included for the final full-text screening step.

To ensure correctness in classification scheme based on data extraction, we defined a data extraction form to obtain consistent extraction of relevant information for answering the research questions.

In the design and execution of this systematic mapping study, there are several considerations that need to be taken into account as they can potentially limit the validity of the obtained results. These considerations are listed below:

- The study includes the papers that are written in English, thus we may have missed relevant papers that are written in other languages.
- The presented classification scheme and obtained results are valid only in our context of computer science and software engineering and do not cover publications from the fields of electronics, mechanical engineering, medical sciences, physics and others.
- The study considers the papers that are available electronically. There is a chance that some relevant papers are not published on-line due to confidentiality or other reasons or have not been scanned and stored in the searched electronic databases. This systematic mapping study does not extend to such scenarios.
- We excluded non-peer reviewed scientific studies, book chapters, books and short papers because they would not provide reliable information for our study.
- The search string was used to search in keywords, titles and abstracts. It is possible - or even likely - that the search string may have failed to identify some relevant papers.
- We proposed a technical classification with clear definition for each category in the classification. Despite the experience of the researchers, some papers were difficult to categorize due to unclear boundaries between some classification categories, and also due to the way the information was presented in those papers.
- The comprehensive selection of included databases resulted in a huge set of potentially relevant publications. The number of analyzed and selected publications is still huge (328). We assumed that the selected pool of publications is representative for the aim of this study and can cover the objectives of the study. Thus, we did not apply any backward search in the references of the included publications.
- As it is known that abstracts do not always reveal the true content of publications, it is possible - or even likely - that we might have excluded a publication with poor abstract but valid content.

VIII. CONCLUSION AND FUTURE WORK

The main objective of this systematic mapping study is to obtain a holistic view of the state-of-the-art research in managing service-level agreements (SLAs) for cloud services

in the Internet of Things (IoT) context. We have identified 328 primary studies, covering a spectrum of approaches with specific perspective or focus. These approaches vary in terminology, descriptions, artifacts and involved activities, yet beyond these differences, we find approaches that share a lot in common, e.g., focus, goal and application context. We extract these commonalities and summarize the studies into seven main categories of technical classifications, i.e., SLA management, SLA definition, SLA modeling, SLA negotiation, SLA monitoring, SLA violation and trustworthiness, and SLA evolution. We have found that most of the studies address aspects related to SLA negotiation, SLA violation and trustworthiness, as well as SLA monitoring. Considerably few studies address the SLA evolution perspective. Addressing various perspectives, these primary studies contribute with models (frameworks 41%), methods (techniques/approaches 44%), metrics (7%), tools (4%) and others (4%). Of these 328 studies, we have identified five research types, which are solution proposal (81%), validation research (3%), evaluation research (9%), experience paper (2%), and conceptual (philosophical) proposal (4%).

The results of this systematic mapping study have implications for both practitioners and researchers. The practitioners can use this mapping study as a source to search relevant approaches for handling specific SLA management perspectives. For researchers, the analysis of the primary studies indicates a number of challenges and topics for future research. The classification of research types in this mapping study indicates that most of the approaches in managing SLAs are applied in academic or controlled experiments with limited industrial settings, rather than in real industrial environments. Thus, more evaluation research needs to be undertaken together with practitioners. The classification of contribution type in this mapping study indicates that many studies focus on proposing models and methods to manage SLAs, however, there is a lack of adequate tool support for managing the various aspects and complexities involved in the SLA management. Therefore, special research attention to developing good tool support would facilitate practitioners more effectively in their SLA management endeavor. Moreover, the multi-faceted aspects of SLA management with respect to, e.g., SLA definition, SLA monitoring, etc., implies the need for being able to qualitatively or quantitatively assess quality of service if it is provided on the same level as what has been defined in SLAs. However, very few studies (7%) look into concrete metrics to address this issue. To summarize, in future we can expect more evaluation research work, case studies, and more in-depth research on metrics definition and tool development to support SLA management in IoT applications based on cloud services.

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