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Fog Computing Challenges: A Systematic Review

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Abstract

Internet of Things (IoT) applications continue to grow at a rapid scale. However, current cloud centric IoT architectures are not feasible to support the mobility needs as well as latency requirements of time critical IoT applications. This has restricted the growth of IoT in certain sectors. This paper investigates the fog-computing paradigm as an alternative for IoT applications. There is a need to systematically review and synthesize fog computing concerns or challenges for IoT applications. This paper aims to address this important research need using a well-known systematic literature review (SLR) approach. Using the SLR approach and applying customized search criteria derived from the research question, 17 relevant studies were identified and reviewed in this regard from an initial set of 439 papers. In addition, 4 papers were manually identified based on their relevance. The data was organized into four major challenge categories. The findings of this research paper can help practitioners and researchers to understand fog computing related concerns, and provide a number of useful insights for future work. The scope of this paper is limited to the number of reviewed studies from chosen database.

Keywords Architecture, IoT, Cloud Computing, Fog Computing, Operational Process

1 Introduction

There is a growing interest and advancement in Internet of Things (IoT) technology with new opportunities and applications emerging in industries such as healthcare, smart home, manufacturing and agriculture (Bader et al. 2016). Both industry and academia have shown significant interest in IoT. However, a recurring theme of discussion is: how to effectively manage the diverse ecosystem comprising large data volume generated by billions of smart devices. Failure to deliver an appropriate response in real-time adversely influences the business feasibility of time-critical IoT applications. Additionally, the network bottleneck caused by moving sensor data to cloud impedes the efficiency of IoT applications. Fog Computing paradigm, introduced by Cisco (Bonomi et al. 2012) in 2012, is considered as the emergent architecture and solution, which claims to overcome the IoT cloud computing deficiencies by moving the computation services nearer to end users and data sources instead of using centralized cloud based computing servers.

Fog is cloud computing occurring near consumer's network. OpenFog Consortium (OpenFog), founded by Intel, ARM, Princeton University, Dell, Cisco and Microsoft to accelerate fog's adoption, and defined fog as a "system-level horizontal architecture that distributes resources and services of computing, storage, control and networking anywhere along the continuum from Cloud to Things" (Chiang and Zhang 2016). Fog computing's need comes from a growing realization that centralized topologies are not sufficient to serve the large quantity, variations and velocity of data generated by IoT. This is also evident from the recent reports which projected that nearly 40% of worlds IoT generated data will be captured , stored, processed, analysed and handled at the edge of the network or near to it by 2019 (Sabella et al. 2016).

Mobility of "things", location awareness, low latency and bandwidth requirements are some of the salient features of fog computing. With very limited number of use cases of fog in real world (Yannuzzi et al. 2017), it is imperative that we understand the dynamics of distributing storage , communication and computation along the range from cloud to things. Without understanding fog's complex ecosystem involving multiple heterogeneous hardware, software components and process involved, it will not be possible to realize the benefits and promise of fog. Hence, this paper focuses on the following main research question (RQ) with an acute focus on the operational aspects of fog applications – What is known about the challenges of the fog computing paradigm?

In this paper, a systematic literature review (SLR) method is used to find answers to the above-mentioned RQ. This review identified four main challenges of fog enabled IoT ecosystems. The findings of this research paper can help practitioners and researchers to understand the overall operational context of fog for IoT applications and will provide a number of useful insights for future research and development work.

The rest of this paper is organised as follows. Section 2 discusses the research method. Section 3 presents the research findings and then detailed discussion is presented in section 4 before concluding the paper in section 5.

2 RESEARCH METHOD

This paper applied the SLR guidelines which has been addressed in the paper by Kitchenham and Charters (2007) for systematically searching, selecting, reviewing and synthesizing the fog computing challenges from relevant academic and industry publications (2014-2017). This study included the paper written in English language, which were selected from five well-known electronic databases (Table 2). Further, seminal work on fog computing from Cisco (S1), Industry consortium (S4) as well similar studies (S2, S6) were also included. The aim of this paper is to review and synthesise literature deficiencies affecting fog computing. It also explores current solutions that can be used to reduce the undesirable effect of the identified fog challenges.

Based on our research aim, a search string was constructed using Boolean "OR" and "AND" operator: ("fog computing" or "Fog Computing") AND (Problems or challenges or concerns or issues). For AIS electronic library database, a variant of the above string was constructed to ensure important studies are not omitted. To avoid or reduce any researcher bias, other researchers were also involved as peer reviewers to identify and resolve any issues to improve the overall quality of the study. The preliminary search resulted in a total of "439 hits" across five chosen databases with 400 of these being distinct. Figure 1 presents the three-stage selection procedure involving identification, filtering and selection of a paper. This approach was taken to ensure that only studies relevant to the RQ were selected. Table 1 shows the filtration criteria used (e.g. Keyword search in title, keyword search in abstract, exploration of paper contents)

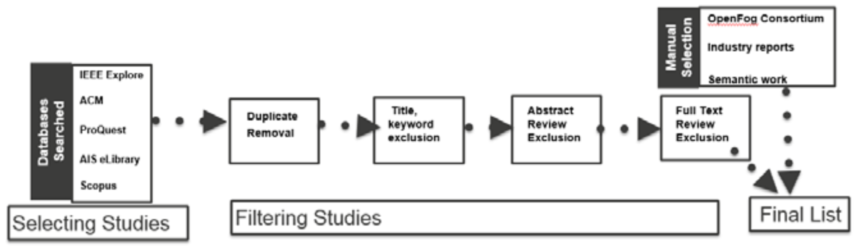


Figure 1: Three stage selection process

Filtration	Method	Assessment Criteria
Stage 1	Identify relevant studies from data sources	Keyword search Published after 2013 Exclude dissertations Remove Duplicates
Stage 2	Exclude studies based on titles	Title matches “fog” search term
Stage 3	Exclude studies based on Abstract review	Abstract matches RQ on fog
Final	Exclude studies based on full-text review	The article addresses the RQ

Table 1. Paper selection criteria

Table 2 gives a breakdown of database specific search results.

Database	1st Filtration	2nd Filtration	3rd Filtration	Final Count
IEEE	179	32	13	7
ACM	44	21	10	2
Scopus	150	95	10	4
AISeL	4	1	1	1
Proquest	62	19	17	2
Others				4
Total	439	228	51	21

Table 2. Search Results

In addition to the above 17 studies, 4 more papers were identified (mentioned as “Others”) through a manual search (S1,S2,S4,S6). This makes the count of 21 final papers selected for this study. All the data extracted from the selected studies was presented in a tabular in table 3. This method helped the identification of basic categories of Fog challenges or concerns as well as policies or best practices to overcome those challenges.

3 Findings

In the final stage, 21 papers were reviewed based on inclusion and exclusion criteria as outlined in the research method. The papers are listed in appendix section. In this section, SLR results are summarized and interpreted to provide useful insights about fog computing challenges. Table 3 presents the identified major challenge categories: (1) security, (2) data governance, (3) device management, and (4) operational technology and process.

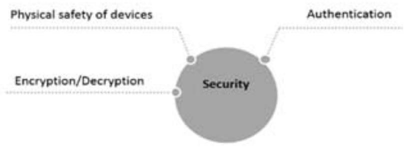
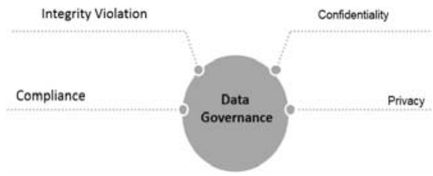
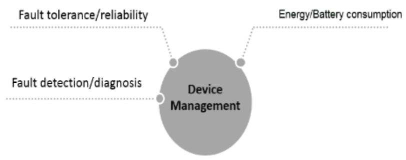
Category	Papers	Count	Percentage	SubCategories
Security	S1-8, S10, S13-14, S16, S18-21	16	76	
Data Governance	S1-8, S10, S13, S19-21	13	62	
Device management	S4-5, S16, S10-11	5	24	
Operational technology and process	S4, S9, S12, S16-17	5	24	

Table 3. Findings – fog computing challenge categories

3.1. Security

Fog inherits some of the problem of cloud computing with a number of studies (76%) highlighting the lack of security in fog devices (Li et al. 2015; Stojmenovic and Wen 2014; Wen et al. 2017). Depending on the use case, devices are setup in public places and subject to tampering due to lack of surveillance. In addition, moving computation logic to the edge of the network, at 3rd party vendor hardware equipment, is also a potential threat (Vaquero and Rodero-Merino 2014). Dastjerdi and Buyya (2016 proposed using public-key infrastructures and trustworthy executing systems in fog as a potential solution to this is problem. But others argued that it might not be sufficient. Some authors pointed out that since distributed fog system is not only vulnerable to attacks like session riding, SQL injection, and session hijacking (Botta et al. 2016). They concluded that applying public key cryptography to all layers was inadequate due to the high computing power consumption requirements. Hence, there is a need for further investigation to equip fog infrastructure with cognitive intelligence necessary to detect threats.

3.2. Data Governance

Some uses case of fog require data to be kept at the local storage and not on cloud (Yannuzzi et al. 2017). This is particularly true in applications involving financial and medical institutions (Dastjerdi and

Buyya 2016). The inclusion of a fog provider further adds complications (Gonzalez et al. 2016) since accessibility of fog network from outside world is a cumbersome process. IDC report (MacGillivray et al. 2016) states that 44 Zetabytes of data is expected to be generated by people, things and process by 2020. Thus , there is a pressing need to identify and address existing gaps to reliably enable the data owner to monitor and control their data. Thus, the data governance involving confidentiality and integrity needs were identified (Shropshire 2014) from a regulatory compliance perspective(Consortium 2017; Stantchev et al. 2015) with proper SLA structure (Wang et al. 2015) covering each point of interaction and each decision point within a process in fog domain.

3.3. Heterogeneous Device Management

In fog, the configuration on billions of diverse "things" must be done in a decentralized manner. Keeping track of the hardware failure information as well as providing software patch updates is as untested terrain as pointed out in the research by (Gonzalez et al. 2016). Open Fog recommends using machine learning techniques to develop a fault tolerant, and fault syndrome detecting framework (Consortium 2017; Dastjerdi and Buyya 2016). For example, in systems involving life critical applications like healthcare, this is crucial and needs to be addressed in order to make fog viable solution for mass scale adoption.

3.4. Operational Process and Technologies

There is lack of concrete process, method and tools that are needed to support IoT application implementation using fog computing (Sarkar et al. 2015). A number of studies have been done in this context that focus on principles, embedded devices, protocols, QoS, security and application domains (Vaquero and Rodero-Merino 2014; Yi et al. 2015) . However, not much work has been done on the study of fog enabled IoT implementation methods. In this regard, Nam Ky Giang (2015) has developed a distributed dataflow framework for IoT application development in fog. In another study (Wen et al. 2017), the authors have described a prototypical system to tackle the implementation challenge. In one of the studies focusing on healthcare sector, authors (Stantchev et al. 2015) provided an overview of the business process model in the fog-to-cloud continuum. Similar concerns are also echoed in the Openfog Reference Architecture.

4 Discussions

The field of fog computing is vast and consists of a number of overlapping technologies. Based on the RQ in hand, we found four major categories of fog computing challenges (e.g security, serviceability, device management, operational technologies and process) as shown in Table 3. These challenges need to be further analysed for developing robust architectures and solutions for fog-enabled IoT applications.

Security (76%) was predictably the most stated challenge in the papers reviewed in this study. The high percentage indicates an urgent need to address this crucial pressing concern of stakeholders. Data Governance, comprising of privacy, confidentiality, compliance and integrity, was another area which emphasized by 62% of the studies. The regulators require guidelines and policies to be implemented by the IoT service providers(Esposito et al. 2017). Reports from Government bodies like EU and US Federal Trade Commission (FTC) acknowledges the risks associated with the realm of privacy and security (Michael S. Smith 2015). Other major categories were Operational process and technologies and device management concerns (24% each).

Fog is a multifaceted ecosystem comprising of diverse technologies, people and processes. Not many studies highlighted the need of service oriented process optimization techniques to support serviceability. Although, these concerns were least mentioned, it does not imply that these are not significant. This, however, indicates the need for more work and studies in the area.

The scope of the paper is limited to research questions in hand and the studies selected for analysis using the SLR method. Moreover, due to the nature of search string constructed and publications chosen, some relevant studies may have been omitted. To alleviate this risk , we have developed, applied search string ,conducted systematic study selection procedure (Table 1,Figure 1) and analysis techniques from a well-known Grounded Theory (GTI 2008) .

Despite its shortcomings, this paper provides some useful insights about the challenges of fog computing in the context of IoT applications. It also draws our attention to the need for future studies on the non-technical aspects of fog computing such as financial and human capital aspects (e.g. skilled people requirements).

5 Conclusion

Fog computing is an emerging topic in IoT domains. Both researchers and industry practitioners seem to suggest that fog enabled IoT will be a key enabler for IoT application across several industry sectors. However, similar to many other technological innovations, fog offers both opportunities and challenges. The effective and informed adoption of fog for IoT requires it's through understanding, in particular its challenges and possible solutions. Thus, this paper identified a set of four major challenge categories of fog computing, in particular security and data governance challenges. This study can be considered as a knowledge base of fog literature for researchers and practitioners. Based on this study results, we intend to conduct further detailed study in fog data governance and business process optimization techniques to support serviceability of fog-enabled IoT applications.

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