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A Systematic Mapping Study of Edge Computing and Internet of Things with the Cloud

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Abstract

Cloud computing is a business paradigm wherein computers and computing related services are provided by Cloud Service Providers to consumers either as software, development platform, or infrastructure. The integration of edge computing and IoT with Cloud opens a new technological dimension and a vista of research opportunities in this field. To determine the research context specifically in edge computing and IoT in relation to the cloud is a rigorous research process, this is where reviews and paper surveys come to play; as they easily help to discover research gaps. This paper aims to conduct a systematic mapping study of integration of Edge and IoT with the Cloud. A combination of topical, research and contribution facets were used to analyze publications of interest in reputable journals, magazines and conferences. Obtained results showed that most publications were on the topic of Applications in terms of Tool and Model, with 11.21% and 17.76% respectively. They were closely followed by publications on Architecture in terms of Model and Tool with 11.21% and 5.61%. Opinion papers were the least in the aspects of Architectures. In addition, there were more publications on Evaluation and Solution research with respect to Application with 9.92% and 14.5% respectively. Most papers on Ubiquitous Networks were in the area of Validation research with 5.34%. Furthermore, there were more work on Optimization in the areas of Philosophical, Evaluation and Experience studies, with 7.62%, 6.11% and 6.11% respectively. The output of this research is to be of benefit to research community as it readily points out areas of research drought.

Keywords: Cloud computing, Edge computing, IoT, Systematic mapping.

1. INTRODUCTION

In The cloud is a parallel and distributed computing system which encompasses an assembly of interconnected and often virtualized computers, which is in a dynamic manner provisioned and presented to customers as a single computing resource based on pre-agreed service levels between service providers and the customers [1]. Traditionally, three Cloud service models do exist, namely; SaaS, PaaS, and IaaS. The listed services are rendered to clients in one of private, public, community, or hybrid cloud deployment [2]. Cloud computing now offers some unique experiences and affects lives in completely new ways. Cloud computing has an improved effectiveness and efficient services, it is constantly expanding based on the sophisticated architecture and the accompanying cloud applications [3], [4]. There are numerous research works ongoing in the area of integrating edge computing and IoT with the Cloud. Many works have identified the suitability of the Cloud for IoT. One of such is [5], in which the authors described IoT as being characterized by highly heterogeneous devices, technologies and protocols as well as lacking in scalability and interoperability, both of which are available on the Cloud, thus making the Cloud a perfect fit. In [6], the Cloud is described as a medium being used to bridge the gap between mobile, edge, and fog computing. However, it is worthy of note that virtualization and multi-tenancy are not without security concerns [7], [8]. In [9], the authors presented the concept of sensors as a service. The focus was on the efficacy of using Cloud and IoT to improve resource management in smart cities. Watson by IBM [10], is a commercially available IoT platform hosted in the Cloud and used to actively support IoT development and integration. Similarly, the authors in [11],[12], presented a combined architecture, showcasing how edge and fog devices can be used for analyzing and pre-processing data gathered by IoT devices before sending to the Cloud. Though CSPs make fruitful efforts in the provision of services with strong efficiency and reliability, trust is a big issue for cloud users [13]. These are volumes of research works relating to Cloud, IoT and Edge Computing. However, many of these works are skewed towards certain directions and do not cover the concepts in their entirety. A systematic mapping study is therefore needed, as it provides an overview of works that have been done in these areas of study. Using unique schemes and structures, a systematic mapping study (SMS) is able to categorize works, publications and reports in any given research area. This provides an insight into the frequency of research and a visual summary of the results. The results are usually generated in a pictorial form using a map.

In writing an article or embarking on research in general, a researcher must consider a technical area of interest. This involves many studies in an attempt to understand the topic. This usually entails searching several conference proceedings, journals and even books. In addition, determining an area of interest may also require a lot of search on digital libraries, attending workshops, seminars and conferences. Also, many researchers become interested in particular research in a specific observed phenomenon serving as impetus for a great amount of research in that field of study. In summary, a researcher's basic curiosity about an observed phenomenon typically provides sufficient motivation for choosing a research topic. From the foregoing, it is obvious that the process of determining a research topic is sometimes usually cumbersome.

The systematic mapping process is usually done in facets to allow for consideration of all aspects. Three facets were employed in this study namely; the topic, contribution and research facets. The topic facet was used to extract core aspects of integrating Edge and IoT with the Cloud. The research facet focused on the types of research carried out, while the contribution facets concentrated on the method and model applied. The purpose of this paper therefore, is to conduct a systematic mapping study of the integration of Edge and IoT with Cloud computing. The remaining part of the paper is organized as follows: section 2 examines related work. Section 3 discussed the systematics mapping process. Section 4 presents results and discussion. Finally, the paper is concluded in section 5.

2. RELATED WORK

Within [14], the planning stage of a systematic mapping study was explored. The work identifies the software patterns as evident during the requirement engineering phase of projects, seeking for a comprehension of the roles played by these patterns based on basic parameters required in the development process. A protocol was developed for the study with basic steps to replicate such a work in the research community for a confirmation of the validity of the research. The digital libraries used for the work are ACM DL, IEEExplore, Scopus, and Web of Science. The guidelines laid down in [15] were adhered to for this work.

In [15], a systematic mapping study in software engineering was conducted and is a foundation to many systematic mapping studies. It provides guidelines for the conduct of systematic mapping studies and a comparison of systematic reviews and maps based on the analysis of existing systematic reviews. The work reveals that systematic maps and reviews are not the same, based on goals, breadth, validity measures, and implications and employ different analysis methods.

The work of [16] dwells on the description of the protocol for a systematic mapping study as it relates to domain-specific languages (DSL). The work is channeled towards an enhanced comprehension of the DSL domain of research with a focus on research trend and future direction. This work covers the period of July 2013 to October 2014, and it leverages on three guidelines for performing systematic review which are planning, conducting the review, and reporting such.

The systematic mapping study in [17] is based on the analysis of the use of concept maps within Computer Science. This work delivers a result that centers on collection and evaluation of existing research on concept maps in Computer Science. Five electronic databases were employed for the work. Backward snowballing and manual approaches were used in the searching process. The work shows massive interest and a rich investigation of concept maps, due to learning and teaching supports in that direction. The search strings of the work were applied on Scopus, ScienceDirect, Compedex, ACM Digital Library, and IEEExplore.

Within the research work of [18], a systematic mapping study was used to study how game related techniques have been employed in software engineering education and how these techniques support specific software engineering knowledge domains, with research gaps, and future direction identified. The primary studies of the work anchored on the use, assessment of games and their factor on software engineering education. A total of 156 primary studies were identified in this study based on publications from 1974 to June 2016. The mapping process of the work was done in line with the steps outlined in [15].

The work in [19] did a mapping of power system model based on the provision of an overview of power system models and their applications used by European organizations; analysis of their modeling features and identification of modeling gaps. There were 228 surveys sent out to power experts for information elicitation, while 82 questionnaires were completed and the knowledge mapping was done accordingly.

In [20], a systematic mapping study of domain-specific languages was done with basic interest in the type of research, the focus area and the type of contribution. The work features a search from reputable sources from 2006 to 2012 with the systematic mapping study done based on specifying research questions, conducting the screening, search, data extraction and classifying. The research materials for the work includes: opinion papers, experience papers, philosophical or conceptual papers, solution proposal, and validation research materials.

In [21], the systematic mapping of the literature on legal core ontologies based their work on the concepts of [22]. The work based its search more on "legal theory" and "legal concepts". Also, the selected studies were categorized based on contribution as reflected in language, tool, method, and model. The other steps include identification of the used legal theories in legal core ontologies building process, identification of focus with a clear recommendation to use the two ontologies, and finally the analysis of every chosen research for cogent deductions about legal and ontological research.

The work in [23] is a systematic mapping study that gives a survey of an empirical research in software cloud-based testing in the process of building a categorization scheme and both non-functional and functional testing approaches were investigated alongside the applications of their peculiarities and methods. Their work utilized 69 primary analysis as discovered in 75 research publications and only a fraction of the study brings together precise statistical analysis with quantitative results. Many of the analysis employed a singular experiment for the evaluation of their proposed solution.

In [24], the systematic mapping of cloud computing management based their work on the concepts of [19]. The classification scheme in relation to cloud management discussed service level agreement (SLA) monitoring, security, autonomous management, self-adaptive SLA, architectures and simulations. The selected studies were applied on the contribution facet such tool, method, and model. In addition, the selected studies were used on the research facet, which dealt with evaluation, validation and solution researches.

The work in [25] did a systematic mapping of designs and deployment models for Cloud computing. The categorization scheme considered design, service deployment, implementations, configurations, privacy, security in relation to design and deployment models. A total of 131 primary studies was utilized and the map created in line with the concepts in [19]. The search strings of the work were applied on ScienceDirect, ACM Digital Library, Springer and IEEExplore. From literature, there has been no work focused specifically on systematic mapping study of integrating edge computing and IoT with the cloud.

3. MATERIALS AND METHOD

3.1 Definition of Research Questions (Research Scope)

A systematic mapping study employs a visual representation process to grant insight into materials published in a field of study. This systematic mapping study was carried out using the formal guidelines for a systematic mapping study as described in [15], [26]. It is can be defined as a repeatable process for extracting and interpreting available materials related to a research objective. There are some crucial steps in a typical systematic mapping study [15]. The first step is the definition of research questions in which the scope of the study is outlined. A search is conducted for primary studies in the proposed area of study. The publications found are then screened to determine their relevance to the study. The next step is the key wording, which involves using the abstracts of the papers for designing a classification scheme. The last step is the process of data extraction, which results in the creation of the systematic map.

These steps were rigorously followed in this paper. With respect to the title of this paper and in order to meet the objectives as well as answer the research questions, a total of 131 papers were considered relevant out of an initial search comprising of 1,671 papers covering the period 2000 to 2018. The list of selected primary studies is at the appendix.

3.2. Definition of research Questions

An appropriate research question is essential for a comprehensive study, because the essence of a systematic map is to have an insight into the quality and type of research activities that have been done in a given field of study. These issues determine how the research questions are crafted in order to accurately capture the essence of the study. In this particular study, the research questions are as follows:

RQ1: What areas of integration of Edge and IoT with Cloud computing are addressed and how many articles cover the different areas?

RQ2: What types of papers are published in the area and what particular evaluation and novelty did they introduce?

3.3 Conduct Search for Primary Studies (All papers)

Typically, searching for papers usually involves exploring major electronic databases. However, this can also be accomplished by manually searching through books, printed conference proceedings and journals. For this study, only publications available on digital libraries were considered, thus book and printed resources were excluded. The search utilized 4 major digital libraries because of their high impact factor [27]. The databases and their URLs are as shown on Table 1.

Table 1. Digital libraries used for the systematic mapping study

Electronic Databases	URL
IEEE	http://ieeexplore.ieee.org/xplore
Springer	http://www.Springerlink.com/
ScienceDirect	http://ww. sciencedirect.com/
ACM	http://dl.acm.org/

The search string for this study was designed in terms of outcome, population, comparison and intervention. The keywords used in the search string were taken from every aspect of the structure of the title of the study. For this study on integrating Edge and IoT with Cloud Computing, the search strings used on the selected digital libraries was

(TITLE-ABS-KEY (“Cloud Systems”) AND (TITLE-ABS-KEY (“Edge”) OR TITLE-ABS-KEY (“IoT Device”) OR TITLE-ABS-KEY (“Internet of Things Devices”)).

The searches were performed using the customized search string above on document metadata to ensure that relevant studies were not omitted. For this study on integrating edge computing and IoT with the Cloud all the result from the relevant databases relating to Cloud computing and computer science were examined.

3.4 Screening of Papers for Inclusion and Exclusion

The purpose of the selection criteria is to find and include all papers relevant to a field of study. It is usual to use the inclusion and exclusion criteria to eliminate papers that are not relevant to the study. The inclusion and exclusion criteria are also used to remove papers that are not related to the research questions. Abstracts can usually be considered here as they provide concise yet sufficiently detailed information about the focus of a paper. However, abstracts are not included in papers on editorials, prefaces, summaries, tutorials, presentation slides, and panel discussions; hence, these types of publications were excluded from the study. To this end, the inclusion and exclusion criteria used for this study are detailed on Table 2.

Table 2. Inclusion and Exclusion Criteria

Inclusion Criterion	**Exclusion Criterion**
The abstract explicitly discussed integration of Cloud systems with edge computing and IoT. Furthermore, the focus of the papers is on Cloud, edge and IoT systems.	The papers lie outside the domain of Cloud, edge and IoT computing. The paper does not contribute in terms of integration of the systems.

3.5 Keywording of Abstracts (Classification Scheme)

Key wording of abstracts is a core aspect of the systematic mapping process. Key wording impacts on the building of the classification scheme. The scheme building usually involves the following steps as shown in Figure 1[28].

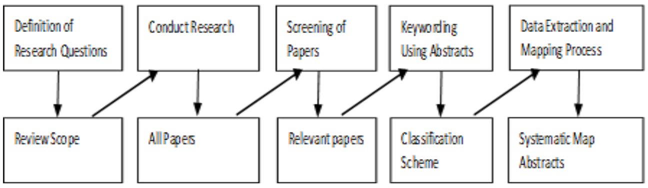

Figure 1. The Systematic Mapping Process [15]

1. Abstract
2. Key wording
3. Classification scheme
   i. Articles
   ii. Sorting articles in scheme
   iii. Updating scheme
4. Systematic Map

Key wording ensures that the scheme considers all the relevant papers. For this study, the process involved studying the abstracts to extract key concepts and words relating to the study. Thereafter, keywords from different papers relating to the study were combined to provide sufficient insight into the kind and contributions of the various research work. This usually used to determine the set of categories to be considered for a study. For some literature, it was also necessary to go beyond the abstracts and also examine the introduction and conclusion to ensure a comprehensive and reliable key wording for this study.

3.5 Research Type Facet with Categories and Description

In this study and in line with [15], three main facets were utilized. The first focused on topics in terms of the integration of Edge and IoT into Cloud computing; the second, the contribution made to the research in terms of model, method, process and metric, while the third involved classification of research approaches. The categories and description of research works as listed in [29] are as following:

1. Validation Research: Unique procedures proposed but yet to be implemented in terms of experiments and possible applications.
2. Evaluation Research: The procedures have been implemented and evaluated. The outcomes in terms of pros and cons have also being discussed.
3. Solution proposals: These papers present unique solution(s) to specified problem(s). The benefits and applications of such solutions are available.
4. Philosophical papers: These offer new ways to examine a problem in terms of concepts and framework.
5. Opinion paper: These does not rely on known methodology or conducted experiments. They simply relates the opinion of the author(s).
6. Experience paper: These papers detail the personal experiences of the author(s). It indicates how something was done.

These categories of research approaches were considered adequate and suitable for use in the classification scheme of this study. The papers included in this study were checked based on the various research categories in the classification of research approaches in [29], and used to represent the research facet.

3.7 Data Extraction and Mapping of Studies (Systematic Map)

During the classification process, relevant papers were sorted into groups. This step allowed for data extraction from various papers that were included in this study. The data extraction process enhances the classification scheme. During this extraction process new categories were added, similar ones were be merged, while others that was not considered sufficiently relevant were removed. This process resulted in 131 shortlisted papers. The process of data extraction was done using Microsoft Excel. The Excel tables contained each category of the classification scheme. The frequencies of publications in each category were combined into a table containing of either “topic/contribution” or “topic/research type”. The analysis focused on presenting the frequencies of publications based on the results obtained from the combined Excel tables. The essence of this was to see which aspects of Edge and IoT integration with Cloud computing were being emphasized more within the various research publications. Consequently, enabling the detection of gaps and providing avenues for further research.

Based on the results obtained from the tables, a bubble plot map was used to present the frequencies. The map consists of a two axes (x and y) scatter plot, with bubbles at the

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intersection of the various categories. The intersections have bubble sizes proportional to the number of articles in each category in the various intersections. There are two halves and three facets. Each half offers a visual map based and the intersection of the topic category with either the contribution or research type category. Hence, making it easy to visualize the different facets simultaneously. Additionally, summary statistics were added to the bubbles, which offered a holistic overview of articles on the field of study at a glance.

4. RESULTS AND DISCUSSION

The analysis of the results focused on presenting the frequencies of publications for each category. This makes it possible to see which categories have been most emphasized in past research. The main focus of this systematic study is on integrating edge, IoT and Cloud computing and this served as the metric used for analysis. The following subsections discuss the result of the study.

4.1 Contribution Category

The systematic map of integrating Edge and IoT with the Cloud is depicted in Figure 2, while the distribution of publications by contributions is as shown in Table 3. On the x-axis of the left half of Figure 2 are the results of the contribution facet. This category depicts the contributions to a study. The result showed that 45.79% of the publications discussed model in relation to Cloud Edge and IoT devices. While those on metric were 1.87%; tool were 24.30%, method were 16.82% and process were 11.21%.

4.2 Research Type Category

The distribution of publications by research type is as shown in Table 4. Depicted on the x-axis of the right half of Figure 2 are the results of the type of researches conducted within the focus area. The results showed that 31.30% of the surveyed papers were solution research, while 25.19%, were evaluation based publications. 15.27% were experience based, 11.45% were on philosophical, 12.98% were on validation and 3.82% were opinion papers.

Table 3 Distribution of Publications by Contributions

Contribution Facet / Topic	Metric	Tool	Model	Method	Process
Architecture	35, 131	2, 5, 6, 23, 31, 51	3, 7, 12, 13, 14, 22, 23, 44, 66, 99, 102, 107	115	
Applications		21, 24, 25, 33, 38, 45, 46, 47, 70, 78, 77, 87	10, 24, 28, 29, 30,37, 48, 53, 54, 58, 59, 71,75,101, 110,115, 116, 117, 118, 121	67, 69, 96, 97,	8, 9
Ubiquitous Networks		84, 92, 104	34, 40, 68, 72, 73, 74, 80, 111,	16, 17, 32, 72, 113	
Implementation		98, 108, 119, 127,	11, 20, 41, 42, 76, 125,	19, 36, 91, 109, 126, 129,	15, 105, 130,
Optimization		4	27, 39, 49, 114	40, 123	18, 26, 56, 60, 81, 94, 100,
Orthogonal					
Percentage	**25.19%**	**12.98%**	**31.30%**	**11.45%**	**15.27%**

Table 4 Distribution of Publications by Research Type

Research Facet / Topic	Evaluation	Validation	Solution	Philosophical	Experience	Opinion
Architecture	2, 5, 6, 7,13, 131	23, 31, 51	3, 12, 35, 44		14, 22, 66, 99, 102, 107	62, 63,
Applications	38, 45, 47, 70, 78, 77, 71, 82, 83, 85, 86, 87, 101,	21, 24, 25, 33, 46	8, 9, 10, 24, 28, 29, 30, 37, 48, 53, 54, 58, 75, 110, 115, 116, 117, 118, 121		67, 69, 96, 97	59
Ubiquitous Networks	32, 34, ,	40,68, 72, 73, 74, 80, 111,	113	84, 92, 104	16, 17	120,
Implementation	98, 108, 119, 127,	36, 109	11, 20, 41, 42, 76, 130, 105, 125, 126, 129,	19, 91		15,
Optimization	1, 4, 43, 50, 52, 79, 112, 128		49, 57, 88, 89, 95, 103, 114	18, 26, 27, 39, 40, 48, 64, 65, 93, 122, 123,	55, 56, 60, 61, 81, 90, 94, 100,	
Orthogonal						
Percentage	**25.19%**	**12.98%**	**31.30%**	**11.45%**	**15.27%**	**3.82%**

4.3 Topic Category and Contribution Facet

The topics that were expected during the classification scheme of integration of Edge and IoT devices with Cloud computing are:

a. Architecture
b. Applications
c. Ubiquitous Network
d. Implementation
e. Optimization
f. Orthogonal

On the left half of Figure 2, the relationship between the topics and contribution facet is shown. For brevity only the Model category would be highlighted. From the Figure, Model discussion contributed 45.79% of the papers reviewed in this facet. 11.21% of the Model papers were on Architecture, 17.76% were on Applications, 7.48% were on Ubiquitous Networks, 5.61% were on Implementation, and 3.74% were on Optimization. Other results of the contribution facets as it relates to topics are shown on Figure 2.

4.4 Topic Category and Research Facet

The right half of Figure 2 depicts the relationship between the topic and the research facet. From the Figure, 31.30% of the publications focused on Solution based research. Of this percentage, 3.05% were in relation to Architecture, 14.50% were on Application,

0.76% were on Ubiquitous Networks, 7.63% were on Implementation, and 5.34% were on Optimization. Evaluation based research ranked second, with publications contributing 25.19% of the papers reviewed. When broken down, 4.58% were focused on Architecture, 9.92% were on Applications, 1.53% were on Ubiquitous Networks, 3.05% were on Implementation and 6.11% were on Optimization.

4.5 Systematic Map of Edge, IOT with the Cloud

The result of the analysis carried out and presented on Figure 2, makes it easy to identify which areas have more emphasis based on the frequencies of publications. From the Figure, it can be identified that most publications were on the topic of Applications in terms of Tool and Model, with 11.21% and 17.76% respectively. They were closely followed by publications on Architecture in terms of Model and Tool with 11.21% and 5.61% respectively. Opinion papers were the least in the aspects of Architectures.

On the right half there were more publications on Evaluation and Solution research with respect to Application with 9.92% and 14.5% respectively. Most papers on Ubiquitous Networks were in the area of Validation research with 5.34%. In addition, there were more work done on Optimization in the areas of Philosophical, Evaluation and Experience studies, with 7.62%, 6.11% and 6.11% respectively.

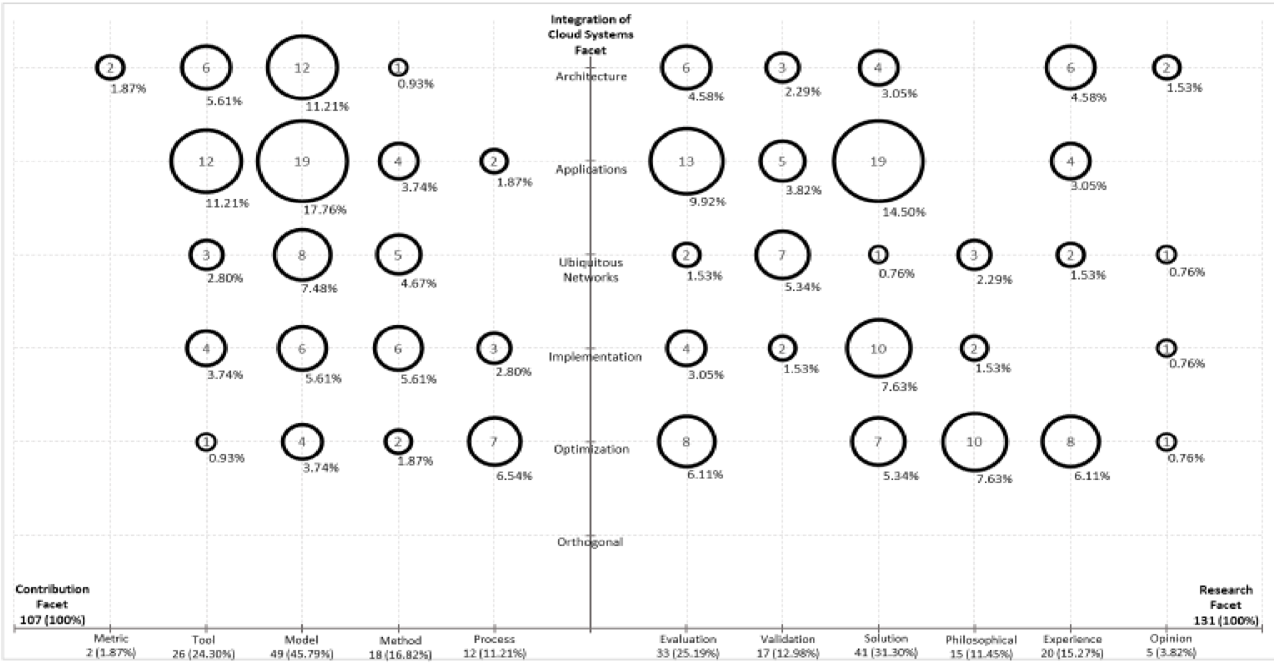

Figure 2 A Systematic Map on Integrating Edge and IoT with the Cloud

On the other hand, there were no articles identified by this study discussing Metric except those on Architecture (1.87%). There were also no articles on Process in relation to Architecture, Ubiquitous Network and Orthogonal. No papers were found on Optimization in terms of Validation research. Just as there were none found on Architecture and Applications in terms of Philosophical research.

Overall, there were more publications in terms of Application. Optimization had the lowest publications in the aspect of Tool. Applications and Implementation had the lowest in the area of Process. Finally, Ubiquitous Networks had the lowest publications in all the research category except on Validation based research. The unique feature about a systematic map is that there are several interesting perspectives to the results generated. The visual appeal of the map also helps to summarize and provide information on potential research areas. There is no doubt that this bubble plot results will be quite useful.

This paper has created a systematic map pointing to areas lacking in studies in terms of systematic mapping study of integration of Edge and IoT with Cloud computing. The relevance of this is that researchers at all levels and industries practitioners can use this as a starting point to conduct further studies. This study provided six classes of studies in the areas of architecture, applications, ubiquitous network, implementation, optimization and orthogonal in relation to the focus of study. In addition, the six classes of study can be discussed either in terms of tool, model, method, metric and process or in terms of evaluation, validation, solution, philosophical and opinion research. These areas amongst others are therefore recommended for future research. The list of included references will also assist intending researchers. The important lessons learnt in this study is that research work is a continuum and it is inexhaustible.

5. CONCLUSION

In Cloud computing, the pay-per-use computing paradigm has continued to serve the interest of individuals and various organizations, providing innovative applications at relatively affordable prices. Beyond applications and infrastructure, several areas of the Cloud are evolving and requiring integration with other environments. IoT computing plays a critical role in achieving this. Edge computing works in tandem with IoT, with the main goal of bringing the computing power of the Cloud, closer to the data source. Integrating Edge and IoT with Cloud offers a formidable dimension to Cloud computing. The large volume of on-going research in this area, should therefore come as no surprise. However, despites the volumes of publications, there are still some aspect where shortages exist. This systematic mapping study has provided a visual representation of some high level topics and the frequencies of publications in the areas selected. This study offers a visual map showing at a glance, areas of higher frequencies of publication and those where there are shortages of publication. Solution and Evaluation-based research are the most common, while most contributions are in terms of Model and Tools. Conversely, little or no attention is being paid to Metric and Process based contributions, as well as Philosophical-based research. These shortages as depicted on the systematic map represent gaps in literature where future research work can be done.

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APPENDIX:

Selected Primary Studies

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