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What do Publications say about the Internet of Things Challenges/Barriers to uninformed Authors? A bibliometric Analysis

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ABSTRACT

The Internet of Things (IoT) as an emerging technology has widely been discussed in the literature in recent years. There are also bibliometric analyses in this regard that illustrate the current status of IoT research. The bibliometric analyses have been used widely by researchers to provide insights into current topics and identify emerging and future research in different fields. As there are challenges or barriers to the use of IoT, it is necessary for researchers to focus on this area. Various studies have discussed IoT challenges/barriers; however, a picture from such research is not accessible in terms of bibliometrics. This research, therefore, conducts a bibliometric analysis on publications that discuss IoT challenges/barriers to identify challenges most discussed in the literature. Results show that challenges/barriers to IoT usually discussed in the literature include security, privacy, trust, standards, architecture, and energy.

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KEYWORDS

Challenges/ barriers to the Internet of Things; IoT; Bibliometrics; Future internet.

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Introduction

The Internet of things (IoT) is the future Internet (Lu Tan and Neng Wang 2010) that can find applications in different sectors (Atzori, Iera, and Morabito 2010). There are researches that discuss the use of IoT in healthcare (Catarinucci *et al.* 2015), libraries (Wójcik 2016), manufacturing (Lu and Cecil 2016), etc. IoT is a network of smart objects (sensors, mobile devises, etc.), which are intelligently connected together via the Internet to provide communication between devices, system components, and people (Dey, Ashour, and Bhatt 2017; Kortuem *et al.* 2009). IoT can attract researchers in different domains as it has impressive impacts on the economy, business, life style, social relationships, etc. (Hung 2017; Rodríguez and Stammati 2018). According to Gartner, there will be more than 50 billion connected things to the Internet by 2020 (Hung 2017). Also, IoT is the key enabler for sustainable healthcare delivery, smart cities, remote monitoring, digital transformation, and industry 4.0 (Aliee, Kashfi, and Farahani 2019; Cetinkaya *et al.* 2019; Mahapatra, Moharana, and Leung 2017; Turcu and Turcu 2013; C. Zhang *et al.* 2017).

Although IoT brings many advantages, there are challenges/barriers that should be addressed. Various researches discuss different challenges or barriers to IoT. Some researchers only focus on limited number of IoT challenges/barriers such as ethics, privacy, and security (Baldini *et al.* 2018; Hofmann, Haustein, and Landeweerd 2017; Padyab and Ståhlbröst 2018; Roman, Zhou, and Lopez 2013; Weber 2010). Other studies discuss some of IoT challenges such as security, privacy, interoperability, regulatory, and development issues (Rose, Eldridge, and Chapin 2015). There are also review papers in this regard. In a literature review, for example, IoT barriers were classified into four major categories including technical (architecture, devices heterogeneity, addressing, data management, hardware, and fault tolerance), privacy and security (data confidentiality, network security, transparency, devices safety, and conflict of interests), business (business, investment issue, economic development, customer experiences, and quality of service), legal and regulatory (data usage, ownership, standardization, cooperation between sectors, and liability), and cultural (education, ethic, trust, and vandalism) (Mohammadzadeh *et al.* 2018).

There are various studies about IoT challenges/barriers, but there is less information about progress of field, core publication sources, contributors, current or emerging trends, etc. This study, therefore, aims to do a bibliometric analysis on the publications related to IoT challenges/barriers to fill current gap. Bibliometrics is defined as *"the field of science that deals with the development and application of quantitative measures and indicators for sciences and technology based on bibliographic information"* (Van Leeuwen 2004). As Onyancha states, "*In bibliometrics, the number of papers, authors or scientists, institutions, journals, subject terms, and citations (including cited references), among others, constitute the units of analysis that have been applied to track the evolution or development of science or disciplines*"(Onyancha 2018). Bibliometric analyses are valuable for scientific community as they provide insights into current topics in the literature and identification of emerging or future research (Ellegaard and Wallin 2015; Hsiao, Tang, and Liu 2015; Huang and Chang 2014; MacDonald and Dressler 2018; Shibata *et al.* 2009). In addition, Mishra *et al.* proposed future research on the IoT barriers (Mishra *et al.* 2016).

In the field of IoT, there are some bibliometric studies. MacDonald & Dressler conducted a bibliometric analysis to identify emerging research fronts regarding IoT (MacDonald and Dressler

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2018). Mishra *et al.* used bibliometric analysis to analyze IoT research from 2000-2015 and clustered IoT research in five clusters based on their bibliometric analysis (Mishra *et al.* 2016). Dadkhah *et al.* analyzed Iranian authors' IoT publications (Dadkhah *et al.* 2018). There are also other bibliometric studies about applications of IoT such as smart city, industry 4.0, smart farm, health, etc. (Konstantinidis *et al.* 2017; Muhuri, Shukla, and Abraham 2019; Suebsombut *et al.* 2017; Trotta and Garengo 2018). In spite of different IoT-related bibliometric studies in the literature, no bibliometric study could be found concerning IoT challenges/barriers. As addressing IoT challenges is a requirement to achieve IoT as good as possible, this research aims to do a bibliometric analysis on publications related to IoT challenges to provide a picture from available research. In addition, most discussed IoT challenges will be identified based on this analysis.

Methodology

Data collection

There are two approaches to collect data:
1) The unawareness situation about IoT challenges/barriers, which has to be searched for using keywords such as *IoT barriers*, *IoT challenges*, etc. This is a practice usually followed by researchers to find relevant publications for systematic review. In addition to providing bibliometric statistical information, using bibliometrics in such situations helps determine the types of challenges/barriers discussed in the literature.
2) The awareness situation with a list of IoT challenges, where the aim is to conduct a bibliometric analysis on the whole literature. In this situation, researchers search for each particular IoT challenge/barrier such as *IoT security*, *IoT privacy*, etc.
Each of the two mentioned approaches provides different search results and different bibliometric results in sequence. The first approach is selected when there is no information about IoT challenges, but when information is available, the second approach seems to be better. The first approach is about publications elucidating IoT challenges/barriers whereas the second one provides more information about challenges/barriers that are known to the researcher. The first approach is mainly chosen by uninformed researchers and those not aware of security challenges for IoT will not search for *IoT security* to find papers discussing IoT challenges/barriers. The current study follows the first approach and aims to conduct a bibliometric analysis on publications addressing IoT challenges for uninformed authors in terms of searching this topic. The reason for selecting first approach is that gaining list of all available challenges is requirement for implementation of second approach. In other words, when researchers aim to identify IoT challenges, they usually should implement first approach, then can use second approach to gain deep understanding. As there are many academic journals in the world (about 5500 journals in the domain of computer science based on Scimago list; www.scimagojr.com), it was not possible for the authors to examine or read all journals/papers, so they usually uses keywords to search for papers in search engines or citation databases. Uninformed authors will, therefore, gain knowledge about IoT challenges using the first approach.

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The web of science (WoS) was selected as the citation database for extracting bibliometrics information. WoS is the world leading citation database with journals covering more than 20,300 titles included via a rigorous selection process. WoS also provides some features that help the analytical purpose (Dabbagh, Sookhak, and Safa 2019). As the current study aims to do a bibliometric analysis on the publications related to IoT challenges/barriers, the following keywords were searched in the WoS: *Internet of Things barriers*, *Internet of Things challenges*, *Internet of Things obstacles*, *IoT barriers*, *IoT challenges*, *IoT obstacles*, *challenges of Internet of Things*, *barriers of Internet of Things, obstacles of Internet of Things*, *challenges of IoT*, *barriers of IoT*, *and obstacles of IoT*. The search results were limited to publications published between 2000 till 2018. The search was done by considering *Title* field in the WoS to find most relevant results. There were researches in the literature for which the *Title* field was used to find relevant publications (de Granda-Orive *et al.* 2013; Huertas González-Serrano, Jones, and Llanos-Contrera 2019; Park and Yoon 2018; X. Zhang *et al.* 2019). The search process provides 467 results. The bibliometric information of these publications was exported as the plain text from in WoS.

Data analysis

The current study aims to perform a bibliometric analysis. There are various tools for bibliometric analysis each providing different capabilities. The Bibliometrix, a library for R statistical tool was used in this research (Aria and Cuccurullo 2017; R Core Team 2018). Bibliometrix provides a variety of analyses on bibliometric information, along with a graphical user interface by Biblioshiny (Aria and Cuccurullo 2017; "Biblioshiny - Bibliometrix for No Coders" 2019). The techniques illustrated in Table 1 were used to analyze bibliometrics information herein (Aria and Cuccurullo 2019; "Biblioshiny - Bibliometrix for No Coders" 2019; Börner, Chen, and Boyack 2003; Bradford 1934; Cobo *et al.* 2011; Cuccurullo, Aria, and Sarto 2016; Lotka 1926; McDonald 2009; Morris and Van der Veer Martens 2008; Peters and Van Raan 1991; Small 1973; 1997; Thompson and Walker 2015).

No.	Technique	Description
1	***Annual Scientific Production***	This shows the number of publications in each year.
2	***Average Citations per Year***	This shows average number of citations collected by articles published in a particular year per citable year (average citations divided by citable years).
3	***Three-Field Plot***	This analysis provides relationships between three selected meta data. This paper presents relationships between keywords, countries, and sources.
4	***Most Relevant Sources***	It shows sources that publish related documents according to their publication number.
5	***Bradford's Law***	This law indicates that publications in a scientific filed are usually published by specific sources. If sources are ordered based on descending publication numbers, the sources can be classified in three groups each containing a third of all publications. The first cluster contains core

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		sources. The mathematical relationship between the number of sources in each group will be as 1:N:N^2.
6	***Most Relevant Authors***	This indicates most relevant authors in the subject and their productions over time.
7	***Lotka's Law***	This indicates that the number of authors who make *n* contribution to a field is $\frac{1}{n^2}$ those making a contribution.
8	***Most Relevant Affiliations***	This denoted most relevant affiliations based on the number of documents.
9	***Country Scientific Production***	This represents numbers of publications in the field by countries.
10	***Most Cited Countries***	This indicates countries whose publications have been cited more than others.
11	***Most Frequent Words***	This determines most frequent words in publications.
12	***WordCloud***	This is the graphical representation of most frequent words in the data.
13	***Word Dynamics***	This illustrates the number of keyword occurrences in each year.
14	***Co-occurrence Network***	This indicates the keywords usually occur togethers. It also determines clusters of words that usually appear together.
15	***Factorial Analysis***	This is used to classify documents based on keywords and to identify subfields in the topic of study.
16	***Thematic Map***	This is conducted to identify various themes in the domain. By doing this analysis in different time spans, it is possible to study evolutions of themes by times.
17	***Co-citation Network***	This shows co-citations between publications in the exported data.
18	***Collaboration World Map***	This illustrates countries that collaborated together on the topic of study.

Table 1. The techniques used to analyze extracted bibliometric data (adapted from the references cited in the text)

Analyses 11-18 can be done on the *Title*, *Authors' keywords*, *Abstract*, or *Keyword plus*. The *Keyword plus* used here are computer generated keywords based on titles of article references. There is research claiming that *keyword plus* to be better or as good as *Author keywords* for bibliometric analysis (E Garfield 1990; Eugene Garfield and Sher 1993; J. Zhang *et al.* 2016).

Results

The first analysis is to identify the number of annual publications, which has grown in recent years (Fig. 1). This is justifiable as concerns about IoT challenges are increasing by growing IoT usage and

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research, leading to considerable research in this area. It also shows the persistence of IoT challenges, which necessitate further discussions and inspections in this regard.

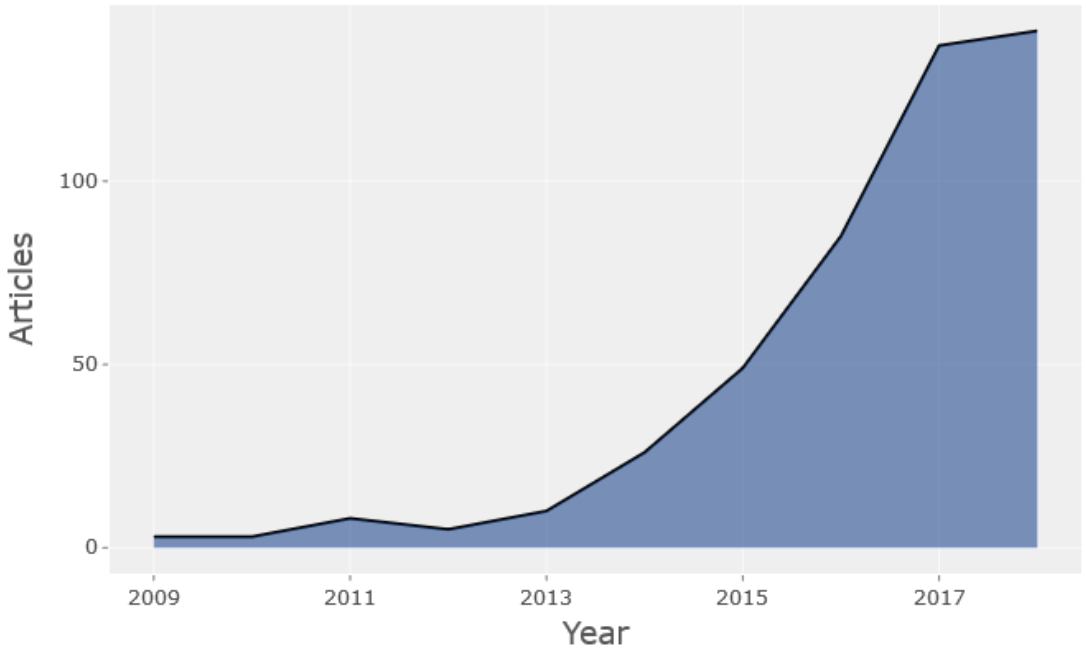

Figure 1. Number of publications in each year

Figure 2 illustrates average citations collected by published articles in a particular year. Articles published in 2012 have maximum average citations per year, which is impressive due to review papers that provide insights into IoT and its challenges for future research. For example, a paper by Miorandi *et al.* published in 2012 is a highly cited article concerning IoT, its challenges, and open questions (Miorandi *et al.* 2012).

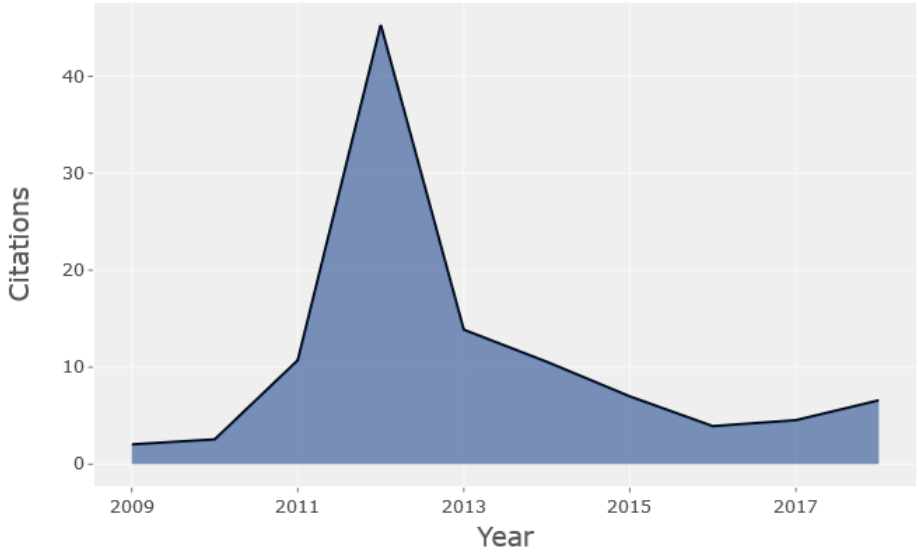

Figure 2. Average citations per year

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It is possible to use *Three-Fields Plot* to identify relationships between three selected metadata including author keywords, countries, and sources (Fig. 3). As shown in Figure 3, it can be observed that researchers of each country used a particular keyword, for example, privacy. Also, it is possible to understand authors from a particular country that contributed in individual journals.

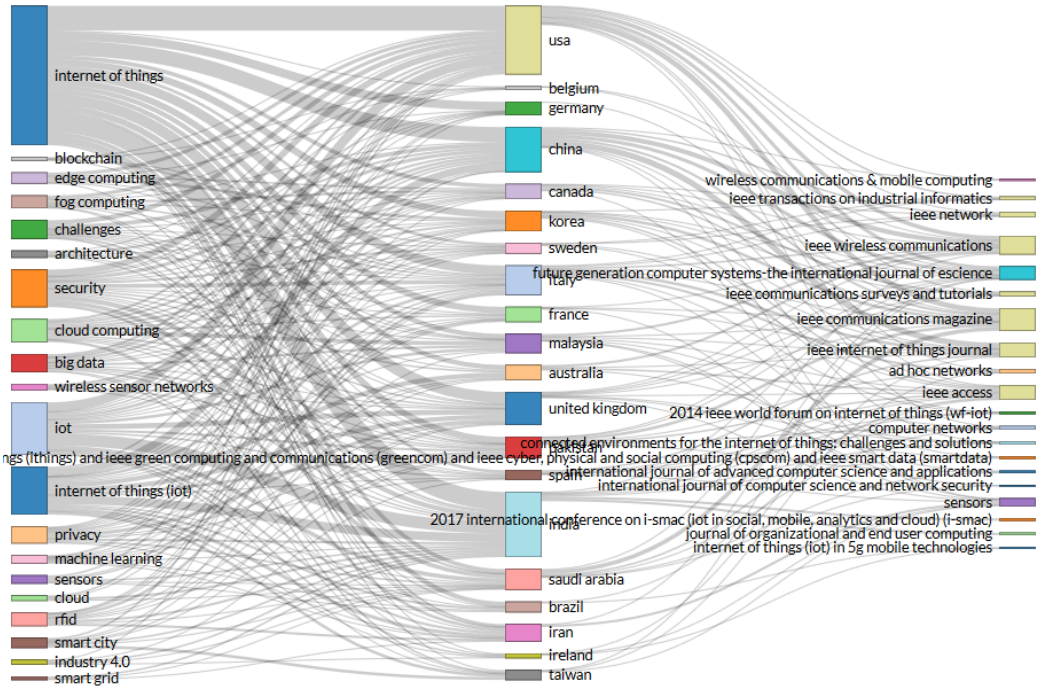

Figure 3. Relationships between three metadata including keywords, sources, and countries

It is possible to identify most relevant sources based on their number of publications. Analysis based on Bradford's law, also discloses these sources. Based on Bradford's law, IEEE journals are most relevant sources to IoT challenges publications (Fig. 4). This implies that we should mainly consider limited number of journals to be updated about IoT challenges.

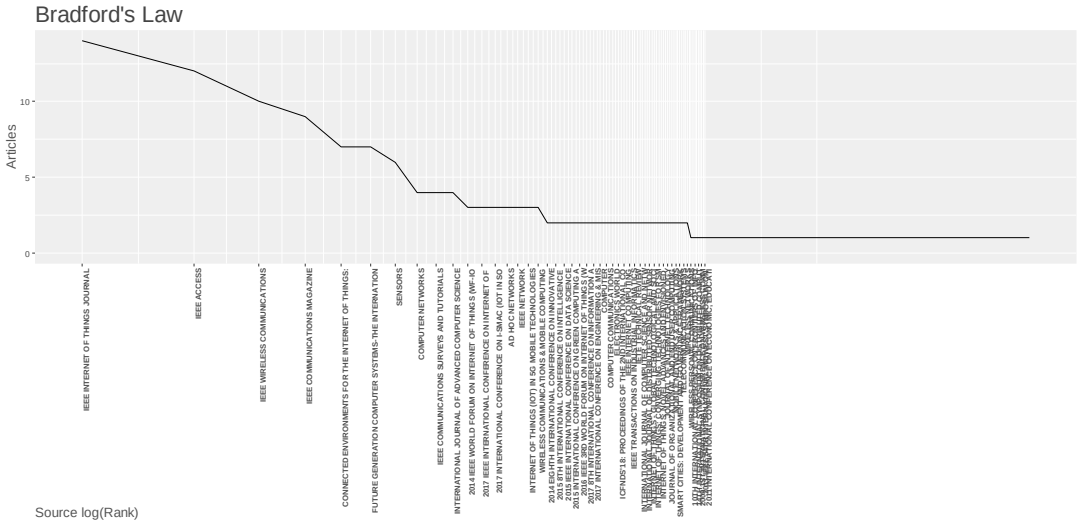

Figure 4. Applied Bradford's law on data (figure supports high quality zoom)

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Most relevant authors are reachable based on their publication number (Fig. 5). It is also possible to apply Lotka's law on the data (Fig. 6). Most authors contributed via a paper in the topic.

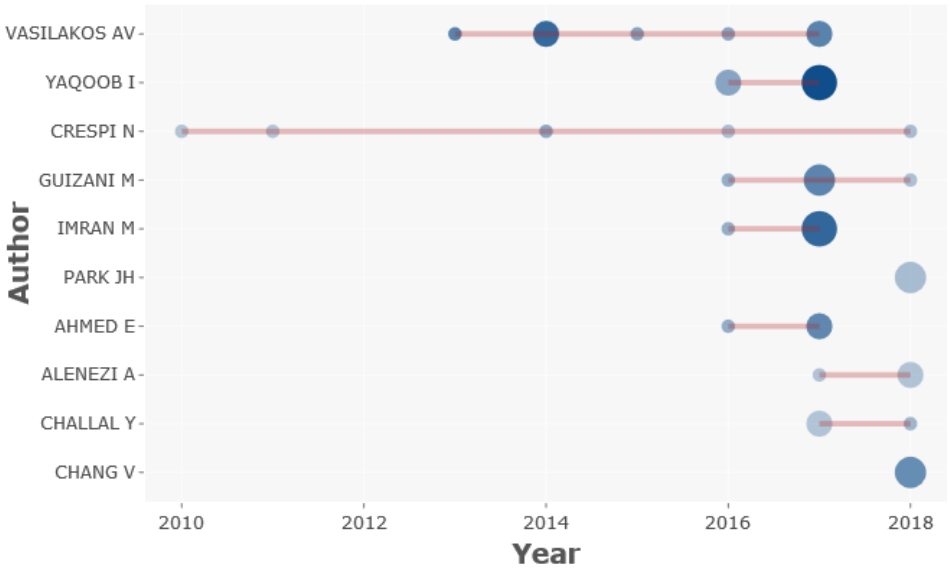

Figure 5. Most relevant authors based on their publication number

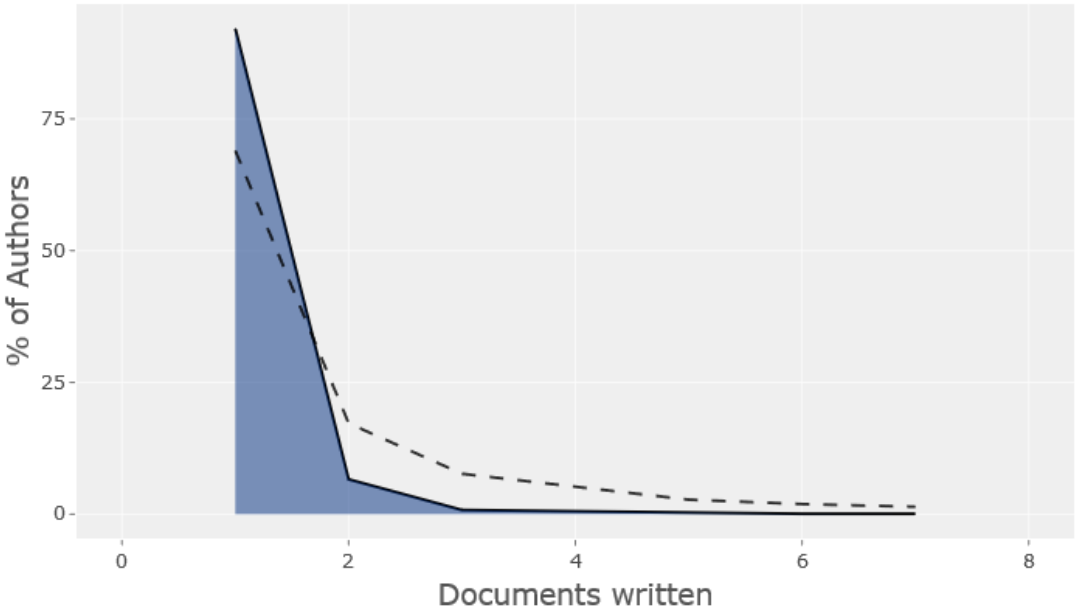

Figure 6. Lotka's law applied to the data

Figure 7 illustrates most relevant affiliations contributed in publications on IoT challenges. Figures 8 and 9 illustrate top countries in terms of scientific productions and received citations. In Figure 8, the darker color indicates further contribution to the topic.

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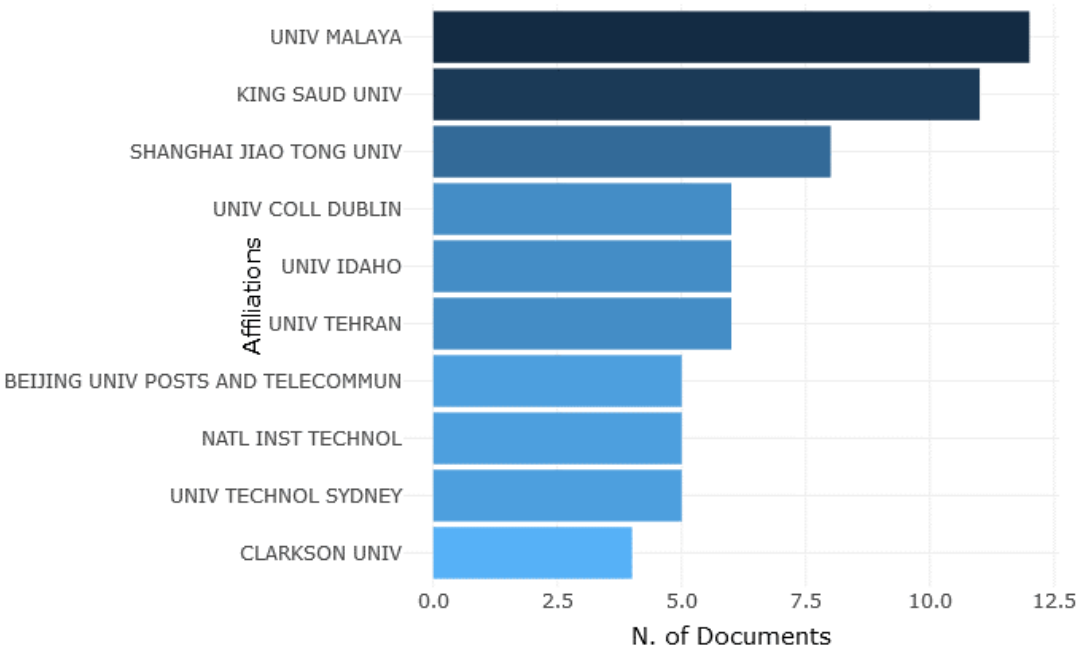

Figure 7. Most relevant affiliations

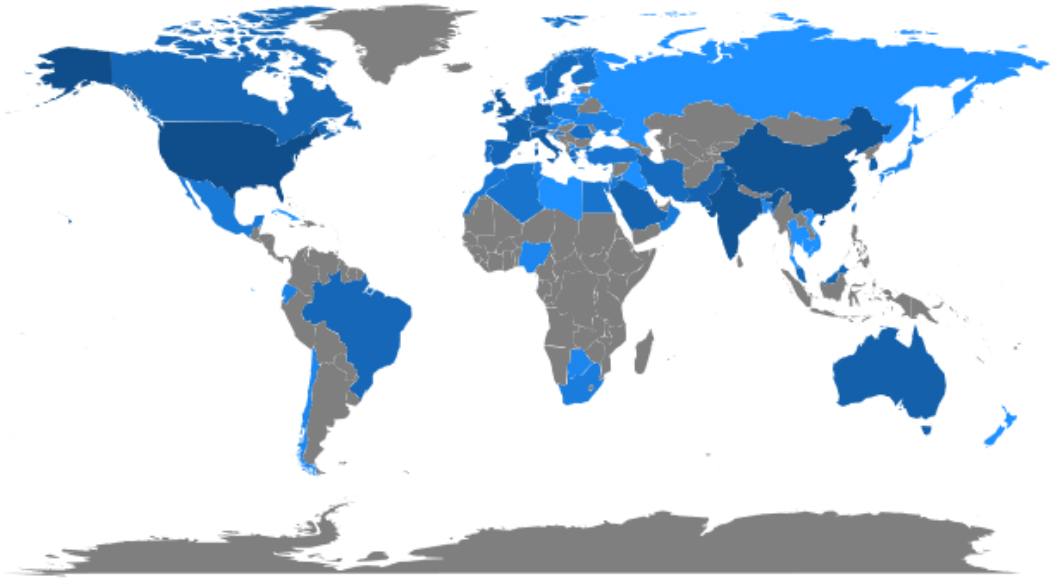

Figure 8. Scientific productions by the country

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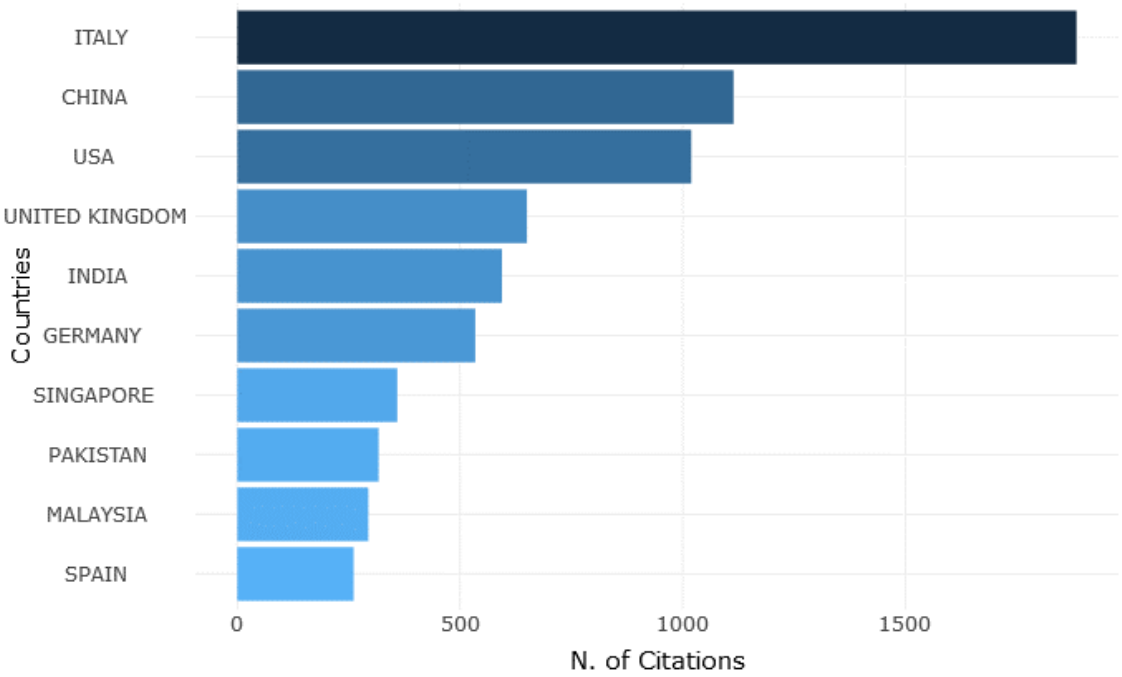

Figure 9. Most cited countries

Most frequent words (keyword plus) are *internet*, *things*, *IoT*, *privacy*, *networks*, *security*, *architecture*, *system*, *management*, *wireless sensor networks*, etc. Figure 10 illustrates the wordcloud of most frequent keywords, somewhat suggesting the challenges of IoT and that there are publications discussing issues related to security, privacy, architecture, trust, and standards. The size of each keyword shows its frequency thus privacy and security are highly discussed challenges.

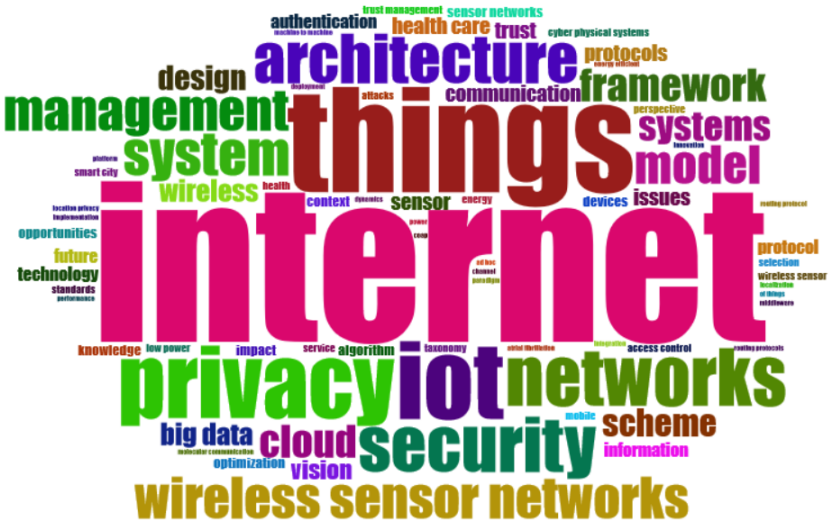

Figure 10. Wordcloud of most frequent words

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Figure 11 shows word dynamics of top frequent keywords, namely Internet, Things, and IoT, which have been increased during recent years. This is reasonable as the increasing number of papers on IoT challenges usually leads to rising number of general keywords in this field. The increased frequency of keywords *architecture*, *privacy*, and *security* in recent years means that researchers have mostly focused on these challenges in their papers. The reason may be the importance of these challenges in comparison to other IoT challenges.

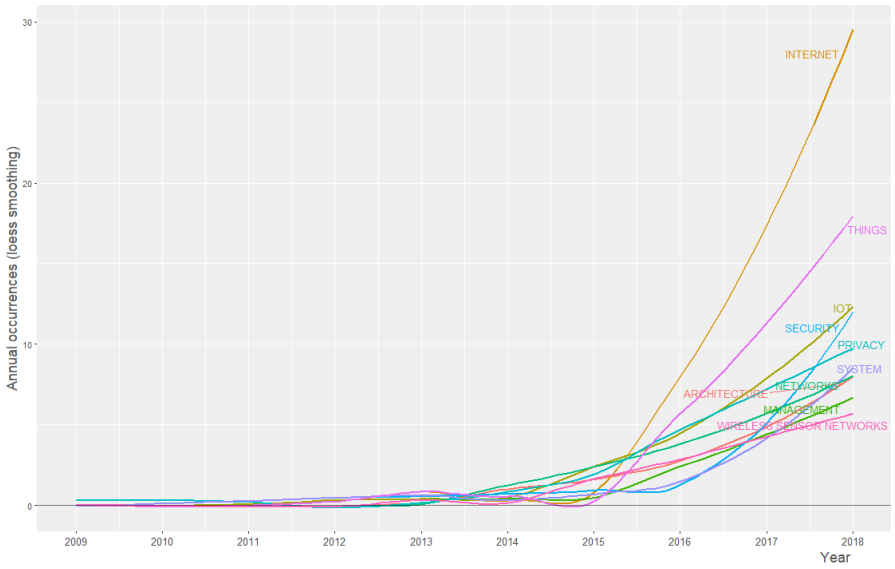

Figure 11. Word dynamics of top frequent keywords

Figure 12 shows the co-occurrence network of keywords. Nine clusters are identifiable by considering these keywords, including IoT architecture (red nodes), services (blue nodes), security and privacy (green nodes), IoT sensor (purple nodes), system (orange nodes), cyber physical systems (brown nodes), supply chain management (pink), IoT (gray nodes), and IoT communication (pale blue nodes).

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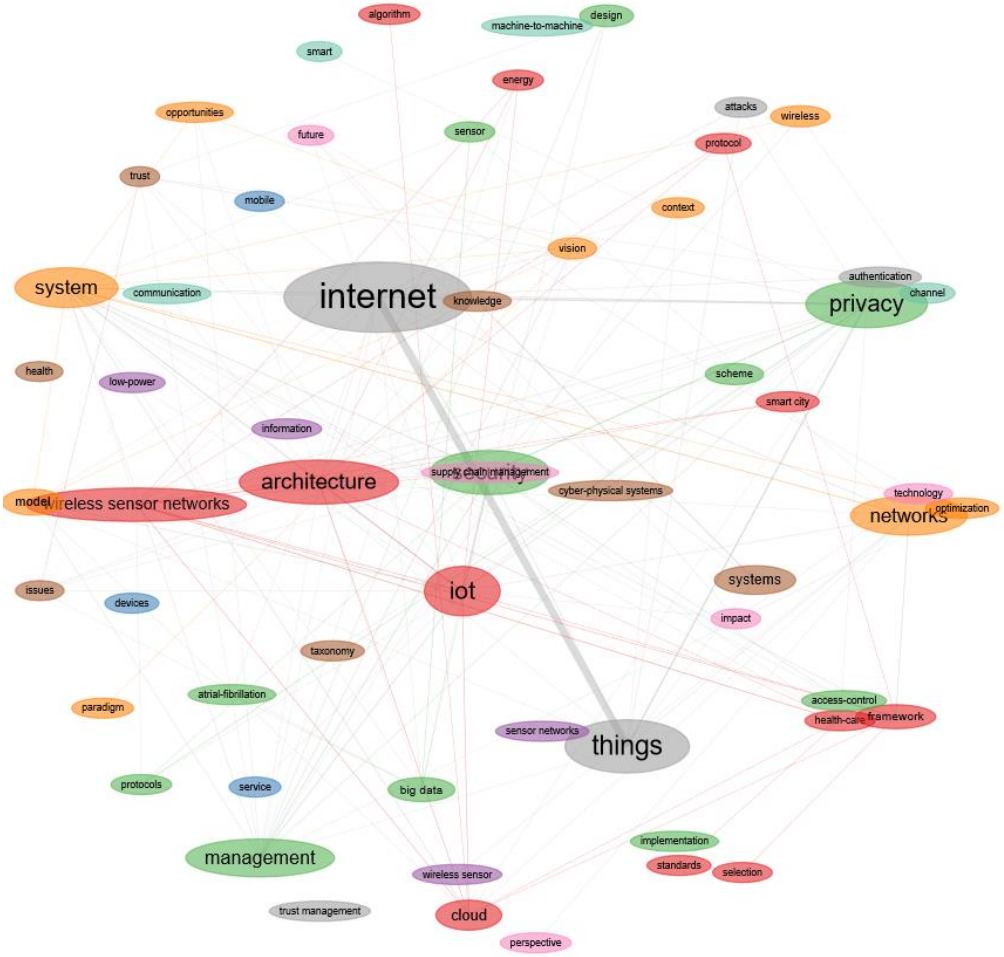

Figure 12. Co-occurrence network of keywords

Factorial analysis is also usable to identify topics in the publications, which could identify six clusters namely technology optimization and impact (orange), opportunity (purple), IoT trust (blue), cyber physical system (brown), IoT standard (green), and IoT challenges including security, privacy, energy, and architecture issues (red color) (Fig. 13).

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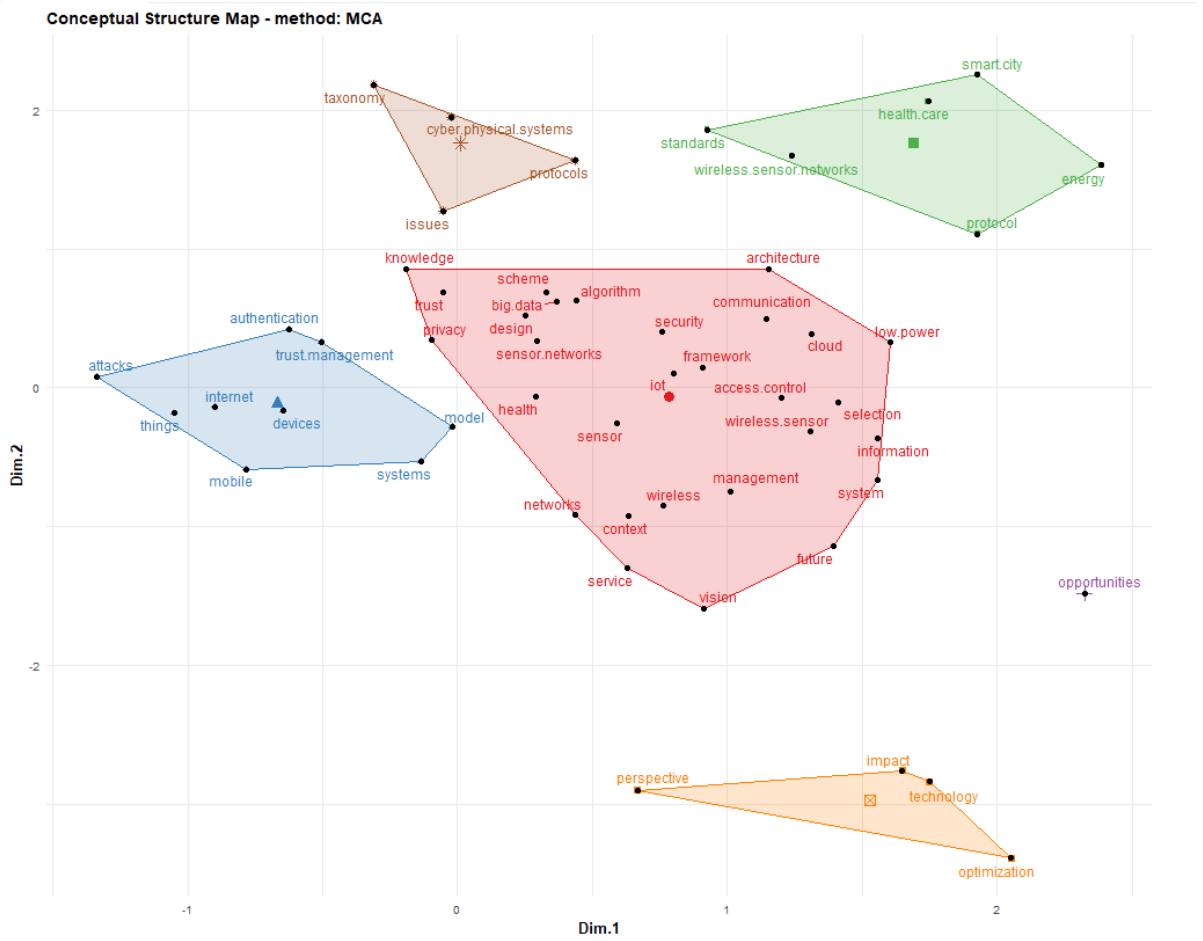

Figure 13. Results of factorial analysis

Figure 14 shows thematic evolution of publications in three periods of 2009-2016, 2017, and 2018. The thematic evolution shows how themes emerge or split over the above years. Figure 14 is not the output image of Biblioshiny as it was redrawn by attaching related keywords of each theme. Based on this figure, it is possible to understand the evolvement of themes based on time. For example, the theme "trust" has emerged as a distinct them since 2017. In 2018, it has been discussed beside authentication. In 2017, security and privacy are usually discussed together, but they are split to two distinct themes in 2018. In the same year, three challenges of IoT trust, security, and privacy appear as three distinct themes. There are themes about "IoT models, management, vision, Scheme", IoT framework, and IoT communication.

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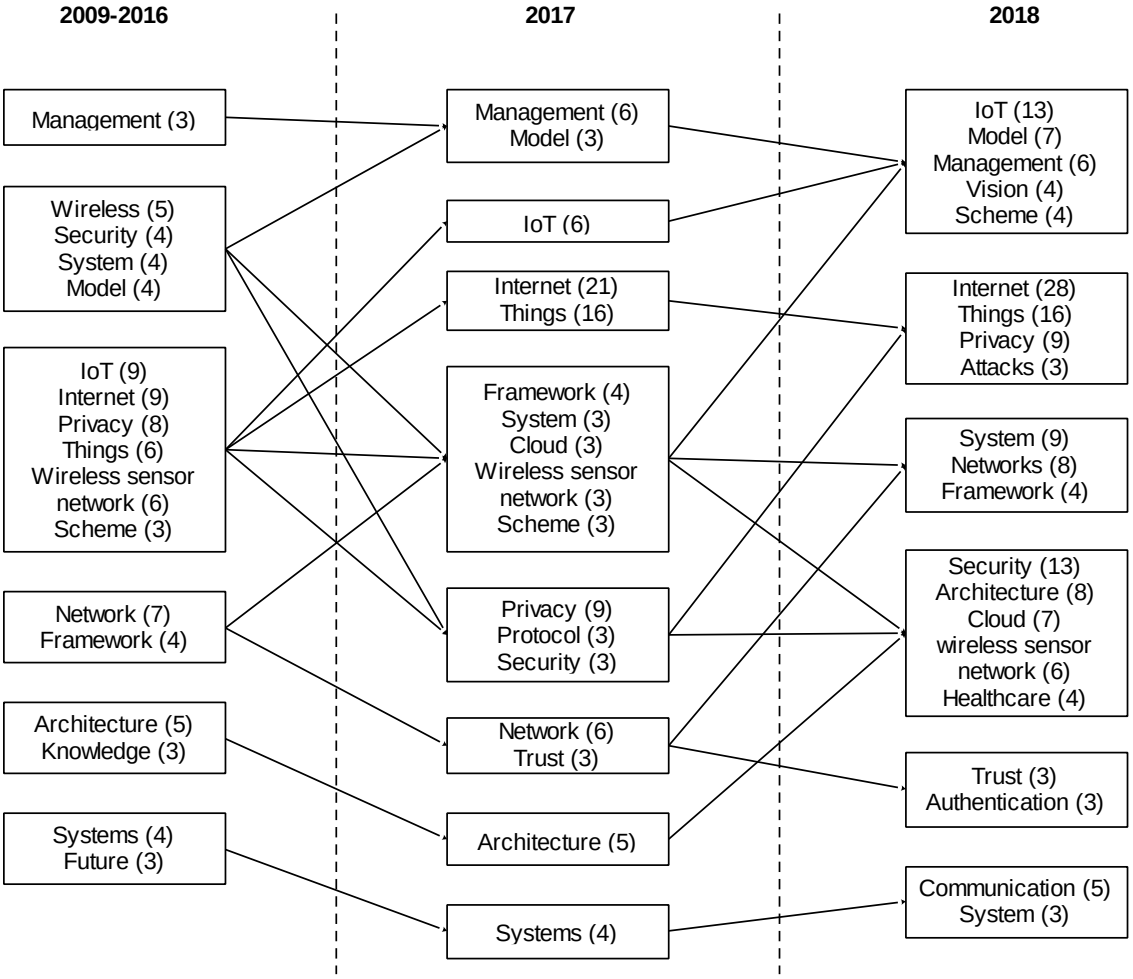

Figure 14. Thematic evolution of publications in three periods of 2009-2016, 2017, and 2018

Figure 15 shows the co-citation network of publications. Cluster 1 (red) is about review and survey papers regarding IoT. Atzori *et al.* and Gubbi *et al.* are the two highly cited documents in this cluster (Atzori, Iera, and Morabito 2010; Gubbi *et al.* 2013). These papers mainly provide a discussion about IoT and its challenges, trends, future research, etc. Cluster 2 (blue) mostly focuses on IoT architecture, middleware, protocol, etc., for example, papers refer to cited references (Palattella *et al.* 2016; Razzaque *et al.* 2015; Sheng *et al.* 2013). Cluster 3 (green) includes papers mainly focusing on IoT security and privacy. Jing *et al.*, Roman *et al.*, and Sicari *et al.* are examples of publications in this cluster (Jing *et al.* 2014; Roman, Zhou, and Lopez 2013; Sicari *et al.* 2015).

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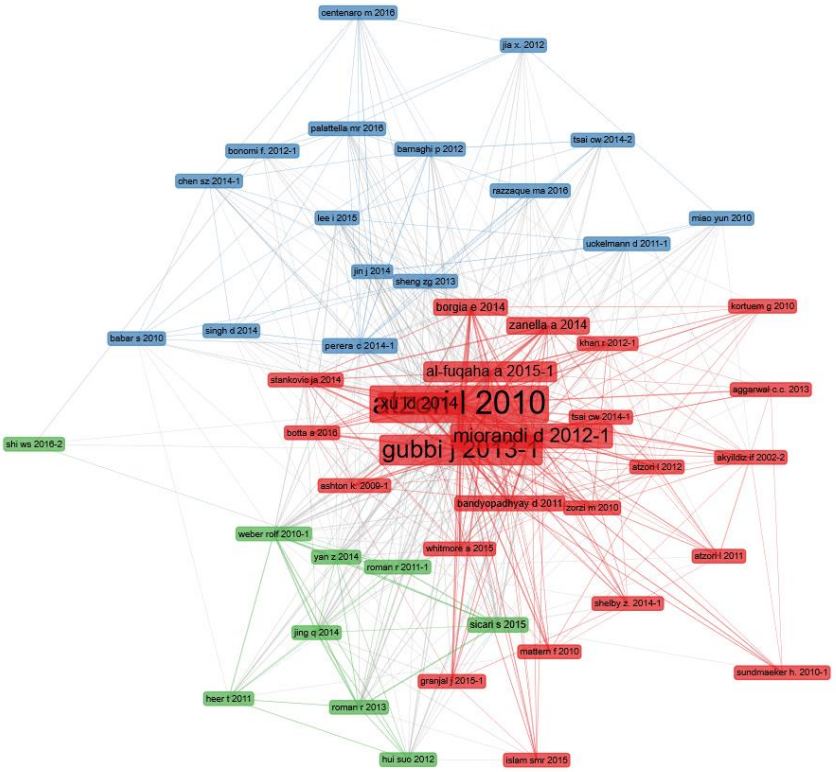

Figure 15. Co-citation network of publications

Figure 16 indicates the collaboration between different countries regarding publications on the topic.

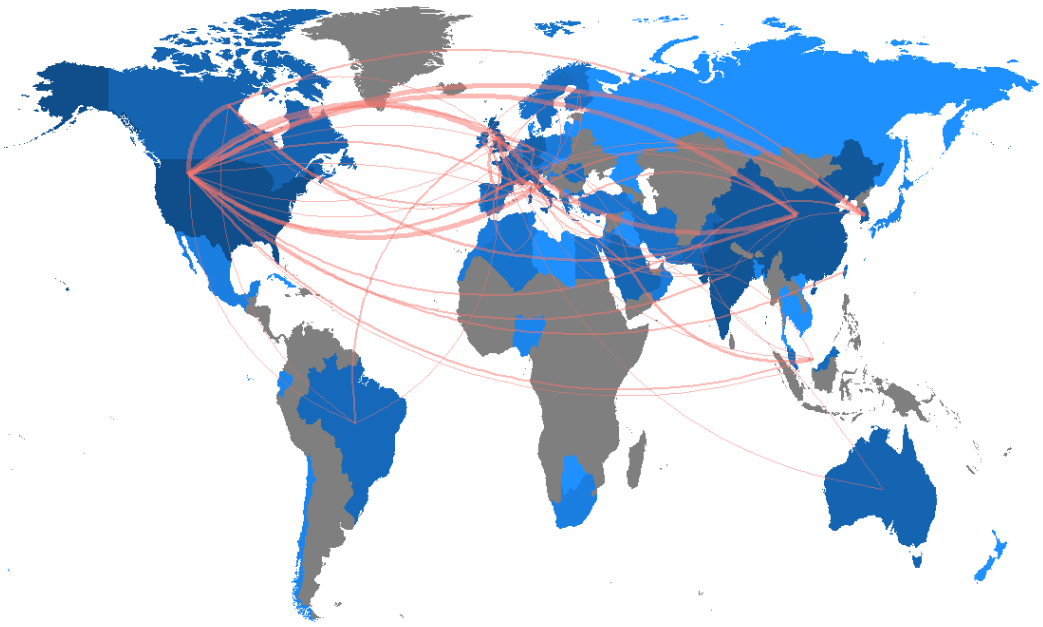

Figure 16. Collaboration between countries on the publications

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Discussion and conclusion

This section discusses the findings of bibliometric analysis on the publications addressing IoT challenges/barriers. The upward growth in the number of papers about IoT challenges is expected to continue as IoT is its infancy and new challenges will appear by growing its usage and applications. Also, there is a need for future identification and discussion of IoT challenges in different contexts. Based on Lotka's law and Bradford's law, limited number of journals currently publish documents related to IoT challenges and limited authors continue their work on IoT challenges. This limited number of contributions is not sufficient to have a comprehensive and detailed view on IoT challenges, which necessitates further research in this regard. At present, many countries have no contribution to IoT challenges, which may be due to the nature of IoT as an emerging technology. Consequently, countries should conduct research for the localization and adoption of IoT.

Figure 10 clearly shows that the current research discusses IoT challenges including security, privacy, and architecture more than others. Figure 11 displays that discussions about security and privacy challenges has increased in recent years. Co-occurrence network of keywords (Fig. 12) also shows discussions about security and privacy challenges in the publications. The results of factorial analysis imply that beside security, privacy, and architecture challenges, there are three new detected challenges including IoT trust, standard, and energy issues. Thematic evolution analysis also illustrates the existence of three distinct themes related to security, privacy, and trust challenges in IoT. Based on Figures 10, 12, 13, and 14, it can be concluded that architecture and energy have also been identified as the challenges of IoT in some related literature (Miorandi *et al.* 2012; Muralidharan, Roy, and Saxena 2016; Ryan and Watson 2017).

To summarize based on analysis, the IoT challenges including security, privacy, trust, standard, architecture, and energy have been discussed in the literature. Concerns about security and privacy have been increased as IoT will provide a wide network of connected devices to the internet. Different researches consider security and privacy as the two different challenges or they discuss them together (Mohammadzadeh *et al.* 2018). People should trust IoT and there should not be uncertainty that violates trust. It is related to security because security is required for ensuring trust. Currently, trust is an open issue for IoT (Frustaci *et al.* 2017). The anarchy due to the lack of a unique standard in the IoT world is a challenge for IoT (Mohammadzadeh *et al.* 2018). The designing and providing a suitable architecture for IoT continue to be an issue in spite of architectures presented in recent years (Mohammadzadeh *et al.* 2018). Power supply is another challenge for the use of IoT. As IoT devices need power to work, there are concerns about continuous power supply. Also, the size of devices may increase due to the size of batteries or power sources (Mattern and Floerkemeier 2010).

Security and privacy are the most discussed challenges in the publications that appear in all analysis results for identifying clusters. The reason may be the importance of security and privacy in comparison to the other challenges. Mohammadzadeh *et al.* investigated on Iranian experts' opinions and concluded that technological and "privacy and security" challenges were of greater importance (Mohammadzadeh *et al.* 2018). Hence, when experts consider a challenge to be important, it is usual to do further research in this area, but it does not mean that we should overlook other challenges. Dadkhah *et al.* analyzed webpages which discussed IoT challenges, they conclude that security, connectivity, data processing, standardization, and adoption are most discussed challenges (Dadkhah *et al.* 2020). Zubiaga *et al.* analyzed tweets about IoT and concluded that IoT security is main concern

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of public perception in the negative side (Zubiaga, Procter, and Maple 2018). Future research should consider security and privacy, and to provide more discussion and analysis on the trust, standard, architecture, energy challenges, and other IoT challenges. Research also is also necessary to identify other IoT challenges. At present, available research about IoT challenges could not provide a comprehensive picture in this regard.

Despite providing interesting findings by the current research, there are some limitations. All the results in this paper are based on the *keyword plus* analysis not on full text papers. As the results are computer generated beside human interpretation, there may be differences with fully human based data analysis. Current research does not claim to cover all IoT challenges as it conducted a bibliometric analysis on samples of related publications. Also, the WoS was used as the source by overlooking other citation databases. The search was conducted in the "Title" field in the WoS to find the most relevant results. This mode of searching presents a sample of publications not all related literature. All the mentioned limitations can be addressed in future research.

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