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Internet of Things: A Scientometric Review

NOTE: this is a modifed version to show ScientoPy commands usage

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Abstract: Internet of Things (IoT) is connecting billions of devices to the Internet. These IoT devices chain sensing, computation, and communication techniques, which facilitates remote data collection and analysis. wireless sensor networks (WSN) connect sensing devices together on a local network, thereby eliminating wires, which generate a large number of samples, creating a big data challenge. This IoT paradigm has gained traction in recent years, yielding extensive research from an increasing variety of perspectives, including scientific reviews. These reviews cover surveys related to IoT vision, enabling technologies, applications, key features, co-word and cluster analysis, and future directions. Nevertheless, we lack an IoT scientometrics review that uses scientific databases to perform a quantitative analysis. This paper develops a scientometric review about IoT over a data set of 19,035 documents published over a period of 15 years (2002–2016) in two main scientific databases (Clarivate Web of Science and Scopus). A Python script called ScientoPy was developed to perform quantitative analysis of this data set. This provides insight into research trends by investigating a lead author's country affiliation, most published authors, top research applications, communication protocols, software processing, hardware, operating systems, and trending topics. Furthermore, we evaluate the top trending IoT topics and the popular hardware and software platforms that are used to research these trends.

Keywords: Internet of Things; IoT; bibliometric; scientometric; ScientoPy; Web of Science; Scopus; applications; smart environments; communication protocols

1. Introduction

Internet of Things (IoT) connects billions of devices to the Internet and has gained tremendous popularity in the past decade as a diverse and pioneering technology. In general, IoT devices combine sensing, computation, and communication techniques to deliver remote data collection and system control. Today, these "things" range from everyday consumer electronics to specialized industrial systems [1], such as fitness-tracking wristwatches [2], transport logistics [3], and smart cars [4] to manufacturing [5] and smart grids [6]. Contingent on implementation, an IoT device may be used for real-time alerts, data archiving, trend analysis, and forecasting by leveraging related technologies such as cloud services [7]. Furthermore, the technology has proven useful for small- and large-scale networks, generating a vast portfolio of enabling hardware and software at various complexities [8,9]. IoT technology has led to solutions in use-cases ranging from smart appliances, utilities, biomedical, industrial, data center management, agriculture, body area networks (BANs), surveillance, and more.

Proliferation of IoT research has contributed to increased availability, affordability, responsiveness, diversity, miniaturization, mobility, and more. Recent studies have demonstrated that IoT, cloud computing, and mobile solutions are among the top technologies that will shape our future in the next 3–5 years [7]. Not surprisingly, connectivity and intelligence are becoming a contributing factor to many designs fueling advanced development. Therefore, the number of new designs and publications categorized under IoT continues to grow exponentially.

Evolution of IoT has spearheaded many research fields such as wireless sensor networks (WSNs), Big Data, and cloud computing. Wireless Sensor Networks (WSN) comprise: sensor nodes, specialized firmware [10], relay devices, and data sinks called a gateway. In addition to facilitating data archiving and local processing, the gateway also acts as a hub that connects to the worldwide web for cloud storage and services using a WiFi or cellular network.The computational complexity of analysis and functional use of the data towards trend and forecasting has grown rapidly, such as in the data center management use-cases [11]. The radio frequency (RF) communication protocols and the interaction between these sensor entities continue to place stringent hardware requirements. Implementations using one software stack over another could achieve better range, quality-of-service (QoS), and spectral efficiency, at the expense, however, of additional processing, storage, power, and form-factor [9]. Additionally, the connectivity and archiving with WSN results in a large volume of samples that create a "big data" challenge.

While IoT is not a new paradigm, it is gaining traction in recent years around the world and yielding extensive research from diverse perspectives. As a result, IoT and similar technologies are progressively challenging topics to review. Starting in 2010, Atzori et al. made a survey about IoT enabling technologies and applications [12]. Then, in 2013, Gubbi et al. defined a cloud center vision for worldwide implementation of IoT, describing the key enabling technologies, applications domains and future directions [13]. In 2014, Borgia presented an extended review about IoT key features, driving technologies and protocols, applications, challenges, IoT initiatives, and research directions [14]. Next, in 2015, Yan et al. developed a co-word analysis, generating seven clusters that represented the intellectual structure of IoT, which were analyzed by a co-occurrence matrix [15]. The following year, in 2016, Mishra et al. composed a bibliometric study about the future vision, applications, and challenges of Internet of Things [16]. In that review, Mishra et al. identified the top contributing authors, key research topics, most influential works, and emerging research clusters, limited only to future vision and applications of IoT, from a sample of 1556 papers from the Scopus database.

As noted above, when conducting a review of IoT publications in recent years, the outcome may vary depending on methodology and time spent browsing through search results. At a minimum, only publications of reputable categories from credible databases should be considered for the review process. For example, conference papers, journal articles, proceedings papers, and reviews are widely accepted as reliable information sources in the industry and academia. Additionally, the manual labor of searching thousands of bibliographic data can be reduced by scripting to facilitate the filtering and comparison activities. This allows the reviewer additional time to investigate supplementary metrics in order to render stronger and methodological conclusions.

Therefore, this paper presents a methodology for citation analysis using search results produced by two scholarly bibliographic databases: Clarivate Web of Science (WoS) and Scopus. To facilitate a thorough review of several thousand publications related to IoT, the study presented herein utilized a novel literature review script called ScientoPy to analyze document bibliographies according to predefined metrics. This scientometrics analysis provides insight into research trends in IoT over recent years by investigating a lead author's country affiliation, most published authors, and prevalence of various research topics. Using the authors' keywords, the research topics inspected in this review include applications, communication protocols, software processing, hardware, operating systems, and trending topics.

2. Materials and Methods

Scientometrics is the study of measuring and analyzing scientific literature by measuring the impact of the innovation and understanding the relevance of these scientific citations to this innovation [17]. Thus, a Python script for scientometrics literature review (ScientoPy) was developed by the authors to analyze content of publications related to the Internet of Things. This ScientoPy script has the capability to:

- Read Clarivate Web of Science and Scopus databases (.CSV files).
- Filter publications by document type.
- Find and remove duplicated documents.
- Graph the history of the top topics (keywords, authors, countries).
- Graph the history of selected items inside a topic.
- Find trending topics using the top average growth rate (AGR).
- Calculate the h-index for authors and countries.

ScientoPy is a Python script that automatically generates and reports the top topics (based on authors' keywords), authors, and countries, along with related documents. This automatic data synthesis avoids potential bias as in individual studies. Nevertheless, author name analysis (such as author top list) has a risk of bias across the studies due to possible similarities in names. The writers of this review know and warn about this possibility of documents' author names similarity, which is part of the limitation of any scientometrics study; thus, in this moment not all the authors and data bases have a unique author identifier, like the ORCID, associated with all entries.

2.1. Data Set

This scientometrics analysis used two bibliographic databases: Clarivate Web of Science (WoS), and Scopus. For the span of 1 January 2002 to 31 December 2016, the following document types were studied:

- Conference Paper;
- Article;
- Review;
- Proceedings Paper.

The search string for this analysis was "Internet of Things". This string was applied to the topic search in WoS and Scopus, which includes title, abstract, authors' keywords, and KeyWords Plus® (for WoS). With this search criteria, the data set was extracted within a day on 6 July 2017. Table 1 describes the number and type of documents found in the two databases totaling 27,120 documents.

Table 1. Type of documents found with the search string "Internet of Things" found in Clarivate Web of Science (WoS) and Scopus within one day on 6 July 2017.

Source	Article	Conference Paper	Proceedings Paper	Review	Duplicated Removed
WoS	3112	0	8215	130	55
Scopus	5283	10,068	0	312	8030

To get the previous table, run the following script, and find the results on ScientoPy/dataPre/PreprocessedBrief

```
python preProcess.py dataIn
```

2.2. Pre-Processing

A pre-processing technique was applied to improve reliability and precision, as detailed in the following sub sections.

2.2.1. Simplify Author's name

In general, scientific and bibliographic databases have the following inconsistencies in authors names:

- Most journals abbreviate the author's first name to an initial and a dot.
- Most journals use the author name's special accents.
- WoS uses a comma between the author's last name and first name initial, but Scopus does not.

These name-related inconsistencies mean that scientometrics scripts cannot find all of the similar author's names. For that reason, ScientoPy script applies the following steps to simplify author's name fields:

- Remove dots and coma from author's name.
- Remove special accents from author's name.

2.2.2. Remove Duplicate Samples

Of the 27,120 original samples, only 72% have an associated DOI for uniqueness. Therefore, duplicated samples were identified by identical title and authors. For duplicated samples in different databases, the WoS publication was kept and the Scopus sample was removed from the set, resulting in remaining 19,035 documents. Table 1 shows the number of documents by type and duplicates removed for each database.

2.3. Times Cited and H-Index

Scopus and WoS databases report the Times Cited Count for each document; however, 47% of the Counts for the same (duplicate) document differ between sources. In such instances, the ScientoPy script selects the highest Times Cited Count, be it from Scopus or WoS, to assign the most favorable value to each document for this metric. Therefore, the h-index for authors and countries is calculated based on these Times Cited Count for the period 2006 to 2016.

2.4. Document's Country

In this study, the document's country was extracted from the primary author's corresponding address. Thus, only one country was associated to each document. Furthermore, some authors use different naming to refer to the same country (such as USA and United States). For that reason, some country names were replaced based on Table 2.

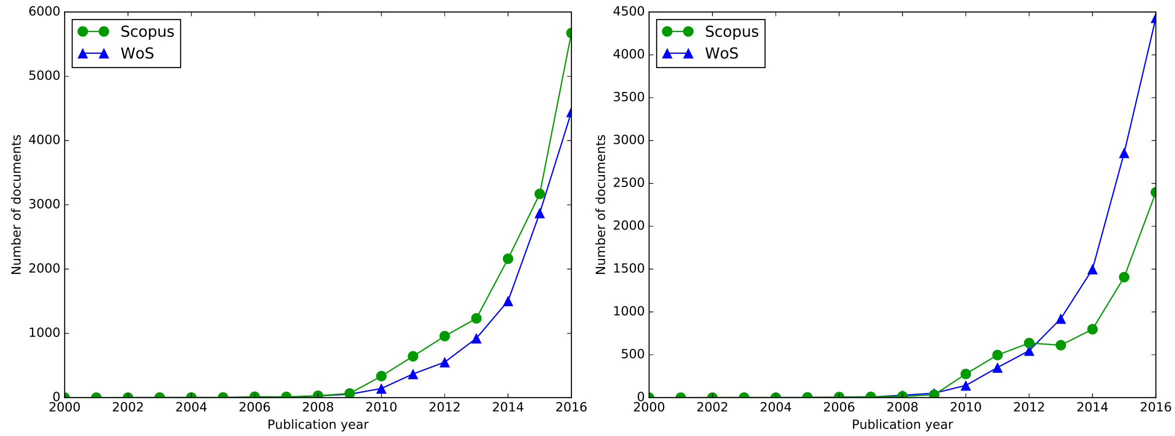
Table 2. Documents' countries names replacing table.

Original	Replacement
Republic of China	China
USA	United States
England, Scotland, and Wales	United Kingdom
U Arab Emirates	United Arab Emirates
Russia	Russian Federation
Viet Nam	Vietnam
Trinid & Tobago	Trinidad and Tobago

In this data set, 95 documents were missing the author's corresponding address to extract the document's country. These samples were discarded for analyses related to country.

2.5. General IoT Publications Growth

The yearly growth of IoT related documents were observed as in Figure 1a, revealing an exponential growth in both databases (WoS and Scopus), without removing the duplicated documents. Figure 1b shows the similar growth after removing the duplicated documents.



(**a**) (**b**)

Figure 1. Documents per year published (WoS and Scopus) with the search string "Internet of Things" (IoT) for the period 2000 to 2016. (**a**) before the duplicates-removal filter; (**b**) after duplicates-removal filter.

To get the previous figure, run the following script for before the duplicates-removal filter graph:

```
python preProcess.py dataIn --noRemDupl
python scientoPy.py dataBase -t "Scopus;WoS" --savePlot "dataBase_preFilter.eps"
```

To get the previous figure, run the following script for after duplicates-removal filter graph:

```
python preProcess.py dataIn
python scientoPy.py dataBase -t "Scopus;WoS" --savePlot "dataBase_postFilter.eps"
```

The first mention of the "Internet of Things" was an article published in March 2002 reported by WoS. Published by Forbes, Schoenberger, and Upbin, this article described how the IoT could be a standardized way to help the computers understand the world [18]. In 2003, Scopus reported a paper from the Institute of Electrical and Electronics Engineers (IEEE) International Conference on Systems, Man and Cybernetic, in which Qui and Zhang showed the design of enterprise web servers supporting instant data retrieval for a product labeled with an Radio-frequency identification (RFID) based smart tag [19]. Scopus reported a second conference paper in 2003 for the 36th Annual Hawaii International Conference on System Sciences, Traversat et al. on the stated the JXTA (abbreviation of Juxtapose) protocols as a foundation of the upcoming Web of Things[20].

In 2004, WoS and Scopus reported the same two articles: ıThe Internet of Thingsȷ by Gershenfeld et al. [21], and ıThe Supply Chainȷ by Luckett [22]. From 2005 to 2016, Scopus reported about 30% more publications than WoS. Nevertheless, for this research, WoS documents were given more priority over Scopus documents during the duplicates-removal process because WoS fields were more complete than Scopus, such as cited references with Digital Object Identifier (DOI) number and subject category. For this reason, Figure 1b shows more documents from WoS than Scopus from 2013 onwards.

3. Country and Author Research Analysis

In this section, analysis was focused on authors and their corresponding country. Below is a graph of the percentage of publications related to IoT each year for the seven countries with the highest occurrence in the data set. A table of the most occurring 50 countries is also provided. Another graph presents the top five authors per year, alongside tables detailing the top 20 authors and 10 most cited author documents for articles, conferences and reviews.

3.1. Country Analysis

A list of the countries with the most associated publications was generated. Figure 2 shows the top seven countries, along with the percentage of documents published per year. In 2002, one article was published on Forbes by Schoenberger; unfortunately, the database does not associate any author address for this document and the sample had to be removed from this data set according to methodology. In 2003, two conference papers were published by United States authors [19,20]. In 2004, there was one review publication in the United States [21] and one article in the United Kingdom [22].

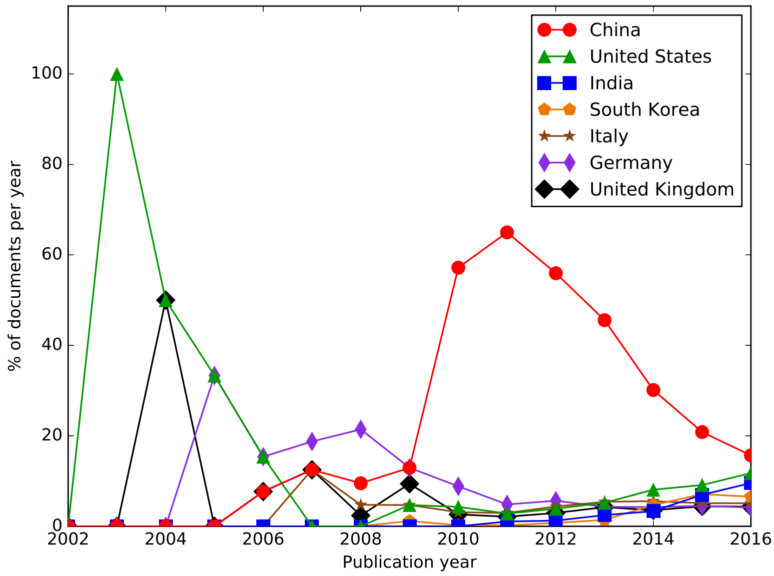


Figure 2. Internet of Things percentage of documents published per year by the top 7 first author's corresponding address country for the period 2002 to 2016.

To get the previous figure, run the following script:

```
python scientoPy.py country --startYear 2002 -l 7 --pYear --savePlot "countries.eps"
```

Germany [23] and Malaysia [24] first appear in 2005, joined by the United States [25]. These three conference papers demonstrated how the RFID can boost Internet of Things for manufacturing, packing, tracking, and automobile logistics. In 2006, the total publications grew from 3 to 12, with more countries participating, such as France [26,27], Switzerland [28,29], and Japan [30]. From 2006 to 2009, Germany led the number of publications with 2, 3, 9, and 11, respectively. During that period, the German author Broll led the citations count with a proposed framework for integrating web services and mobile interaction with physical objects [31].

China drastically increased from 11 to 239 publications from 2009 to 2010, continuing to contribute more than half of the globally published documents between 2010 to 2013. Most of that growth resulted from China's Twelfth 5 Year Plan (2011–2015), which included the development of the Internet of Things [32]. The conference paper "IOT Gateway: Bridging Wireless Sensor Networks into Internet of Things" by Zhu was the most cited IoT paper during this period for China, as it explained how an IoT Gateway could make a bridge between wireless sensors networks and traditional communications networks to the Internet [33].

From 2014 to 2016, China maintained the highest rank, contributing 20% of the globally published documents, as well as a peak in 2016 and h-index of 47. In 2014, the United States was second to China with 187 publications and h-index of 42. India's contributions grew at a rate of 153%, 103%, 286%, and 120%, in 2013 to 2016, respectively, moving from the 8th to 3rd position in 2013 and 2016, respectively. The Indian daily "The Economic Times" forecasted the country is expected to see a rapid 31-fold growth of IoT devices to reach 1.9 billion by 2020 [34].

Expanding the results from Figure 2, Table 3 shows the top 50 countries of the primary author with the average percentage growth and the h-index of each country from the last three years (2014 to 2016). Of the top 10 countries, South Korea represents the maximum average growth with 206%, where the mobile carrier SK Telecom (Seoul, South Korea) launched the first commercial low-cost Internet of Things (IoT) network in 2016 [35]. However, this growth is not reflected yet (next year) in the available literature and thus the data set has an h-index of 16, only half of its successor in this list, Italy. In the same way, this list includes the top growing countries with low h-index but anticipated to be higher next year: Indonesia, Turkey, Russian Federation, and Pakistan.

Table 3. Internet of Things top 50 countries of first author's corresponding address. Country number position (N.), total number of publications (Total), average percentage growth from the last 3 years (2014 to 2016), and h-index (h-ind.) from 2006 to 2016.

N.	Country	Total	Average Growth	h-Ind.
1	China	4822	16%	47
2	United States	1561	116%	42
3	India	1089	169%	15
4	South Korea	894	206%	16
5	Italy	874	61%	32
6	Germany	811	64%	24
7	United King.	711	71%	25
8	France	543	126%	21
9	Spain	463	42%	23
10	Japan	449	166%	11
11	Taiwan	438	68%	16
12	Brazil	272	90%	9
13	Finland	266	50%	20
14	Canada	259	104%	15
15	Australia	249	59%	22
16	Sweden	216	68%	17
17	Switzerland	193	31%	19
18	Portugal	191	45%	13
19	Greece	180	46%	14
20	Romania	169	72%	9
21	Belgium	164	87%	11
22	Austria	146	113%	12
23	Malaysia	137	71%	9
24	Russian Fed.	134	271%	8
25	Ireland	126	116%	9
26	Netherlands	109	122%	12
27	Singapore	109	112%	8
28	Poland	104	77%	6
29	Czech Rep.	101	153%	5
30	Turkey	92	319%	5
31	Pakistan	82	210%	7
32	Saudi Arabia	80	122%	7
33	Norway	72	119%	11
34	UAE	71	180%	6
35	South Africa	60	162%	9
36	Denmark	59	39%	11
37	Tunisia	55	163%	6
38	Serbia	53	−1%	6
39	Croatia	51	159%	6
40	Hungary	51	24%	6
41	Indonesia	51	410%	3
42	Egypt	49	159%	4
43	Morocco	47	163%	4
44	Iran	42	94%	5
45	Colombia	39	146%	3
46	Algeria	38	113%	5
47	Jordan	38	108%	5
48	New Zealand	38	86%	6
49	Mexico	36	172%	5
50	Thailand	32	107%	4

To get the previous table, run the following script, and find the results in results/Country.csv:

```
python scientoPy.py country --startYear 2002 -l 50 --noPlot
```

The International Data Corporation (IDC) predicts that, by 2019, 20% of local and regional governments in Indonesia will use the Internet of Things to turn infrastructure such as roads, street lights, and traffic signals into assets instead of liabilities [36]. In addition, the Dutch IoT start-up, Xeelas (Arnhem, Netherlands), and Turkish group, Sade (Ankara, Turkey), partnered to build Turkey's largest LoRaWAN (LoRa, Long Range Wide-area network network) in Istanbul to enable business, local governments, and conservation groups to collect and analyze from connected devices [37]. In Russia, the Internet of Things market is expected to reach USD 74 Billion by 2023, where the Russian government's Internet start-up fund (FRII) has joined forces with tech giants GS Group (Saint-Petersburg, Russia) and mobile operators to launch a national Internet of Things (IoT) consortium [38]. In Pakistan, by January 2017, 17 Internet of Things start-ups were launched, on their own or incubated, at Plan9 (Lahore, Pakistan), NEST i/o (Karachi, Pakistan), and i2i (Islamabad, Pakistan) [39].

3.2. Author Analysis

The data set analyzed here includes 31,422 authors of the 19,035 documents related to Internet of Things. In addition, 592 of these authors have 10 or more publications in WoS or Scopus. Figure 3 shows the top five authors with the most published documents per year. Y. Zhang was positioned first with 130 published documents related to IoT and RFID, security, electric vehicle, artificial immune system, smart grid, and cloud computing. In 31 documents, Y. Zhang appeared as a first author. His most cited document is the article titled "Toward Cloud-Based Vehicular Networks with Efficient Resource Management" [40] with 96 citations.

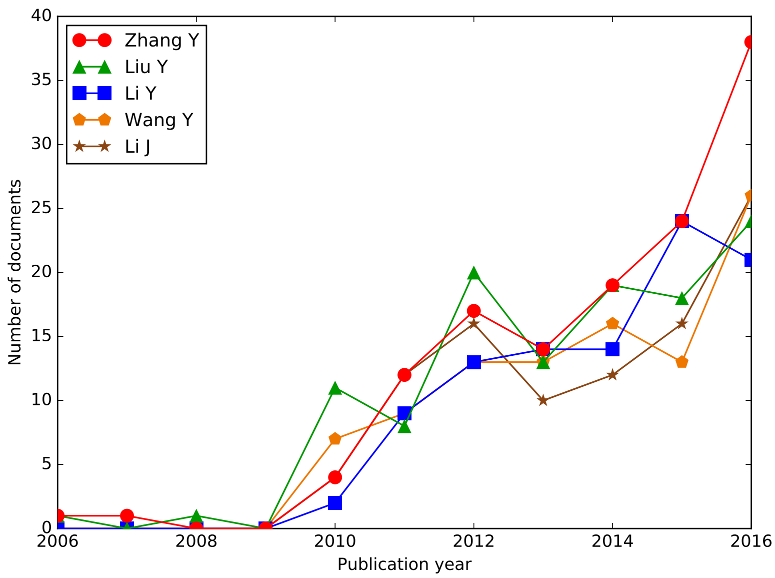


Figure 3. Internet of Things top 5 authors with most documents published per year, for the period 2006 to 2016.

To get the previous figure, run the following script:

```
python scientoPy.py authors --startYear 2006 -l 5 --savePlot "authors.eps"
```

Y. Liu is positioned second with 115 documents, of which 36 list him as the primary author. His publications are more focused on hardware such as Raspberry Pi, test bed, optical communications, ZigBee, and RFID. The article titled "IOT gateway: Bridging wireless sensor networks into Internet of Things" is his most cited document with 134 citations [33]. Y. Liu shares the authorship in four publications with the first author in this list, Y. Zhang.

Y. Li is the third in this list with 97 publications, with 37 as the primary author. His focus was on RFID, big data, and databases. "Towards a theoretical framework of strategic decision, supporting capability and information sharing under the context of Internet of Things" [41] is his most cited publication with 39 citations. With the same number of publications, 97 and 39 as the primary author, Y. Wang is next in this list. His research is related to RFID, smart gird, security, logistics, and big data. His most cited document is [42] with 16 citations. Lastly, fifth on this list is J. Li with 96 publications with 33 as the primary author. His papers related to RFID, ZigBee, and standardized breeding, with his proceedings paper in [43] being his most cited paper with 97 citations in this set.

Table 4 shows the top 20 authors with the most published number of documents, along with the author's h-index in IoT, most cited document, and top research topics. Nevertheless, the two-top h-index authors in this case are not in the top 20 number of documents. L.D. Xu is the author with the highest h-index of 21 and 33 publications. Similarly, L. Atzori has second place in h-index of 14 and 41 documents.

Table 4. Internet of Things, top 20 authors with most publications, total number of documents, h-index, most cited document, and top related research topics for the period 2006 to 2016.

N.	Author	Total Documents	h-Index	Most Cited Document	Top Author Topics
1	Zhang, Y.	130	12	[40]	RFID, security, Electric vehicle
2	Liu, Y.	115	11	[33]	RFID, name service, ZigBee
3	Li, Y.	97	9	[41]	RFID, big data, database
4	Wang, Y.	97	5	[42]	RFID, smart grid, secirity
5	Li, J.	96	9	[43]	RFID, ZigBee, standarized breeding
6	Zhang, J.	82	6	[44]	RFID, WSN, monitoring system
7	Wang, J.	80	8	[45]	RFID, 5G, sampling
8	Zhang, L.	79	13	[46]	Cloud computing, cloud manufacturing, ZigBee
9	Wang, X.	78	6	[47]	RFID, ZigBee, service selection
10	Chen, Y.	72	8	[48]	RFID, WSN, ZigBee
11	Jara, A.J.	72	13	[49]	6LoWPAN, smart cities, big data
12	Zhang, X.	72	6	[50]	Logistics, RFID, WSN
13	Li, H.	71	7	[51]	RFID, authentication, security
14	Wang, H.	70	9	[52]	RFID, monitoring, cloud computing
15	Li, X.	67	8	[53]	RFID, recommendation, smart grid
16	Liu, J.	65	10	[54]	Cloud computing, RFID, security
17	Kim, J.	62	7	[55]	WSN, video streaming, HEVC
18	Wang, Z.	60	8	[56]	RFID, GPRS, EPC network
19	Liu, X.	59	9	[57]	Cloud computing, RFID, Landsenses ecology
20	Kim, D.	58	7	[58]	EPCIS, 6LoWPAN, security

To get the previous table, run the following script, find the results in results/Authors_extended.csv and results/Authors.csv, read the keywords and some papers to extract manually the top author topics

```
python scientoPy.py authors --startYear 2006 -l 20 --noPlot
```

Table 5 shows the most cited papers for three document types (articles, conference/proceedings and reviews). Atzori et al. surveys IoT vision and enabling technologies [12]. Second in articles, Gubbi et al. describe a cloud-centered vision for the worldwide implementation of IoT [13]. Miorandi et al.'s article surveys on technologies, applications and research challenges for IoT [59]. For conferences and proceedings, Bonomi et al. describe the Fog computing characteristics and its role in IoT [60]. Tao et al. propose cloud computing, Internet of Things, virtualization, and service-oriented combination technologies with advanced manufacturing models and enterprise information technologies to generate a new manufacturing model, called cloud manufacturing

(CMfg) [61]. Tan and Wang show a skeleton of the Internet of Things with an application model that can apply to automatic facilities management in the smart campus [62].

Finally, on the reviews side, Gershenfeld et al. present a review about the Internet-0 (Internet-Zero) protocol, whose approach for the reduced complexity of the IP stack extends the notion of internetworking to interdevice [21]. Meng and Ci mention that the data type and amount is growing at a high speed due to emerging services such as cloud computing, IoT, and social media. Thus, they review the concept of big data and describe a new era for data handling [63]. Lastly, Aziz et al. surveys the topology control techniques for extending the lifetime of battery to power WSNs for the Internet of Things battery-powered devices [64].

Table 5. Internet of Things top 10 documents with most citations, divided by document type, including position number (N.), first author, document reference, times cited, publication year, and first author corresponding address for the period 2002 to 2016.

N.	First Author	Document Reference	Times Cited	Publication Year	Country
Articles documents					
1	Atzori L	[12]	3239	2010	Italy
2	Gubbi J	[13]	1369	2013	Australia
3	Miorandi D	[59]	721	2012	Italy
4	Kortuem G	[65]	506	2010	United Kingdom
5	Ganti RK	[66]	494	2011	United States
6	Bobadilla J	[67]	482	2013	Spain
7	Li B-H	[46]	471	2010	China
8	Perera C	[68]	454	2014	Australia
9	Zanella A	[69]	404	2014	Italy
10	Chen M	[70]	370	2014	China
Conference and proceedings documents					
1	Bonomi F	[60]	508	2012	United States
2	Tao F	[61]	228	2011	China
3	Tan L	[62]	169	2010	China
4	Spiess P	[71]	156	2009	Not specified
5	Mainetti L	[72]	142	2011	Italy
6	Zhu Q	[33]	134	2010	China
7	Dohr A	[73]	132	2010	Austria
8	Kovatsch M	[74]	112	2011	Switzerland
9	Khan R	[75]	101	2012	Italy
10	Su KH	[43]	97	2011	China
Review documents					
1	Gershenfeld N	[21]	271	2004	United States
2	Meng X	[63]	172	2013	China
3	Aziz AA	[64]	139	2013	Malaysia
4	Domingo MC	[76]	138	2012	Spain
5	Borgia E	[14]	132	2014	Italy
6	Hancke GP	[77]	101	2013	South Africa
7	Wang ZL	[78]	98	2010	United States
8	Wang SH	[79]	83	2015	United States
9	Keoh SL	[80]	69	2014	Singapore
10	Malhotra A	[81]	64	2013	United States

To get the previous table, open on a spreadsheet editor the results/papersPreprocessed.csv file, short the documents by document type, and then by cited by.

4. Research Topics

IoT has a broad spectrum of research fields such as applications, smart objects, communications protocols, software processing, devices hardware, and operating systems. On the data set analyzed here, most of the authors include their research topic in the document keywords. In this section, author keywords were analyzed to find the trends in the different research topics. For Scopus, the regular authors' keywords were used, and similarly for WoS. KeyWords Plus from WoS were discharged because they are index terms created automatically from significant, frequently occurring words in the titles of an article's cited references, and they are less comprehensive in representing an article's content [82]. The top 1000 keywords were extracted, manually classified in the different research field, and grouped by plural-singular similarity and/or abbreviations. For instance, the keywords WSN, wireless sensor network, and wireless sensor networks were grouped into the WSN keyword. The following subsections describe the trend of the research topics in different fields, based on the top authors' keywords publications per year. Figure 4 shows the general top 10 authors' keywords.

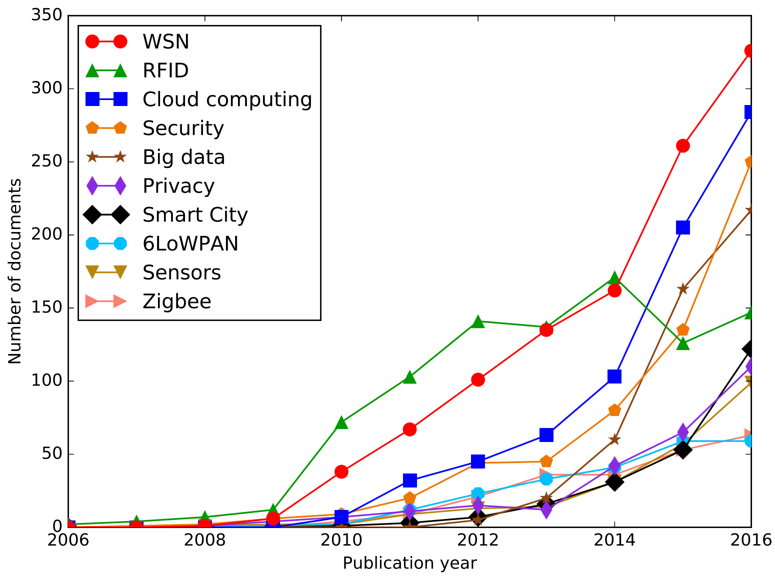


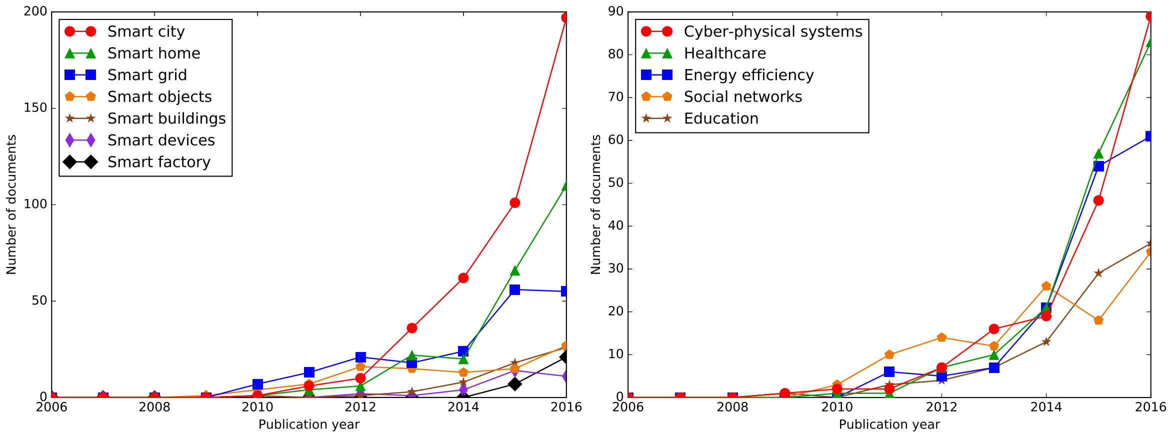
Figure 4. Internet of Things top authors' keywords documents published per year, excluding the keywords: Internet of Things, IoT, Internet of Things (IoT), and The Internet of Things, for the period 2006 to 2016.

To get the previous figure, run the following script:

```
python scientoPy.py authorKeywords -t \
"WSN,Wireless sensor network,Wireless sensor networks; \
RFID,RADIO FREQUENCY IDENTIFICATION;Cloud computing;Security;Big data; \
Privacy;Smart City;6LoWPAN;Sensors;Zigbee" --startYear 2006 --savePlot "keywords.eps"
```

4.1. Applications

There are several application fields related to IoT research and development. In this section, the authors' keywords were analyzed to find the top specified applications. Figure 5 shows the trend of these applications in documents per year. Furthermore, Figure 5a presents the applications that start with the word "smart", and Figure 5b those that do not.



(a) (b)

Figure 5. Internet of Things top applications based authors' keywords in documents per year, for the period 2006 to 2016. (**a**) applications that start with "smart" (**b**) applications that do not start with "smart".

To get the previous figure, run the following script for smart applications:

```
python scientoPy.py authorKeywords -t \
"Smart city,Smart cities;Smart home,Smart homes;Smart grid,Smart grids;\
Smart objects,Smart object,Smart enviroments,Smart enviroment;\
Smart buildings,Smart Building;Smart devices;Smart factory" \
--startYear 2006 --savePlot "smart_things.eps"
```

To get the previous figure, run the following script for not start smart applications:

```
python scientoPy.py authorKeywords -t \
"Cyber-physical systems,CYBER PHYSICAL SYSTEMS,CPS;\
Healthcare,E-Health;Energy efficiency;\
Social networks,Social networks,Social media;\
Education,Learning,E-Learning,mobile learning" \
--startYear 2006 --savePlot "applications.eps"
```

In the data set, 1052 documents were found for applications that start with "smart". Smart city is the top one in this list, with 413 documents, and a sigmoid growth in exponential phase, 95% more publications in 2016 vs. 2015. A.J. Jara has the most number of documents in this field with 12 publications. His most cited document [83] refers to Smart and Connected Communities as a concept that is evolving from Smart cities. The leading country in this application is Italy with 50 publications, and the most important correlated topics are Big data [84–86], Cloud computing [87,88], and Smart grid [89,90]. Similarly, Smart home has a linear growth, with 230 documents, and 111 in the last year, with China as the leading country. The most important related topics for Smart home are security [91–93], ZigBee [94–96], and activity recognition [97–99].

In contrast, smart grid is a topic that has not demonstrated continuous growth. In 2012–2013, the documents published per year decreased from 21 to 13, and in 2015–2016 from 56 to 55. Nevertheless, an overall 194 documents were registered on this topic, with China as the leading country. The term smart grid refers to "a next generation power grid that uses two-way flows of electricity and information to create a widely distributed automated energy delivery network" [100]. Within IoT, the research on smart grids are related to security [101–103], cloud computing [104,105], and privacy [103,106,107].

According to Dumitrache, ıCyber-Physical Systems (CPS)s are physical, biological and engineered systems whose operations are monitored, coordinated, controlled and integrated by a computing and communication coreȷ [108]. Publications of this topic related to IoT have a sigmoid growth in exponential phase, with 182 publications in 2016, noting United States as the leading country with 34 documents. The most important related topics are: Industry 4.0 [109˘112], big data [113˘115], and security [116˘118]. Next, Healthcare and E-Health related to IoT exhibited a sigmoid growth in a transitional phase, with a total of 180 documents, and India as the leading country with 20 publications. Different IoT technologies are applied in this area such as sensors [119], RFID [120˘123], 6LoWPAN [124,125], and wearables [126,127]. The third most growth topic was energy efficiency with 154 documents, and China and Italy as leading countries with 18 and 17 publications, respectively. Energy efficiency as an application for IoT is related in this data set with the following topics: smart buildings [128˘130], energy harvesting [131˘133], and RFID [134,135]. Social networks (or Social media) is another application for IoT, with 117 documents, and Italy as the leading country with 23 publications. Among the top related topics in this field are trust management [136–138] and recommendation systems [139,140]. Education, Learning, E-Learning, and mobile learning is the fifth top application in this list, with 93 publications and the United Kingdom as the leading country with 12 documents. The most popular related topics with education are: augmented reality [141–143], context aware [144–146], and near field radio technologies such as RFID [147–149] and Near Field Communication (NFC) [150,151].

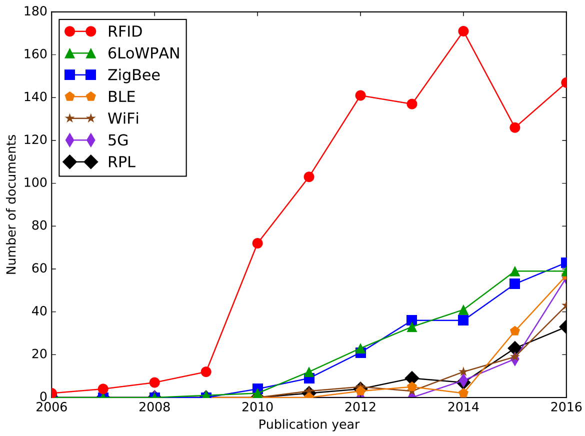
4.2. Communication Protocols according to Open Systems Interconnection model (OSI model)

Regarding telecommunications systems, the Open Systems Interconnection model (OSI model) describes the communications process in seven layers which are divided into media layers (Physical,Data, and Network) and host layers (Transport, Session, Presentation, and Application) [152]. In this review on IoT, the most used communication protocols are divided into these two layers (see Table 6). Figure 6 shows the yearly trend of the different communications protocols for media layers in Figure 6a and host layers in Figure 6a.

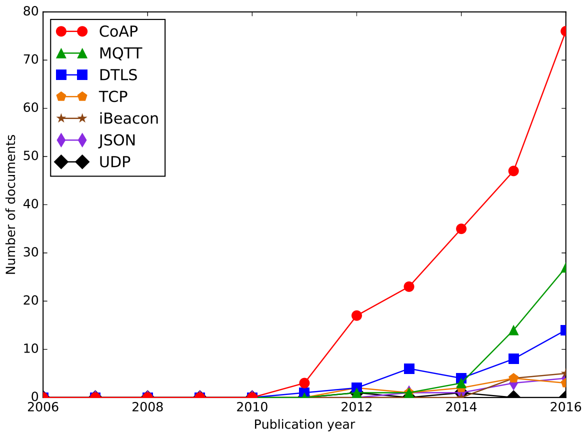
Table 6. Internet of Things Open Systems Interconnection model (OSI model) communication protocols.

	Layer	IoT Communication Protocols
Host layers	7. Application 6. Presentation 5. Session	CoAP, MQTT, JSON, iBeacon
	4. Transport	TCP, UDP, DTLS
Media layers	3. Network	IPv6, 6LowPAN, ZigBee, BLE, RPL
	2. Data link 1. Physical	RFID, 802.15.4, WiFi, BLE, 5G

Abbreviations definition: Constrained Application Protocol (CoAP), Message Queue Telemetry Transport (MQTT), JavaScript Object Notation (JSON), Transmission Control Protocol (TCP),User Datagram Protocol (UDP), Datagram Transport Layer Security (DTLS), Internet Protocol version 6 (IPv6), IPv6 over Low-Power Wireless Personal Area Networks (6LoWPAN), Bluetooth Low Energy (BLE), Routing Protocol for Low power and Lossy Networks (RPL), Radio-frequency identification (RFID).



(a)



(b)

Figure 6. Internet of Things media and host layers communication protocols based on authors' keywords in documents per year, for the 2006 to 2016 period. (**a**) media layers' communications protocols (**b**) host layers' communication protocols.

To get the previous figure, run the following script for media layers' communications protocols:

```
python scientoPy.py authorKeywords -t \
"RFID,RADIO FREQUENCY IDENTIFICATION;6LoWPAN;\
ZigBee;BLE,Bluetooth Low Energy;WiFi,Wi-Fi;5G;RPL" \
--startYear 2006 --savePlot "media_layers.eps"
```

To get the previous figure, run the following script for host layers' communication protocols:

```
python scientoPy.py authorKeywords -t \
"CoAP,Constrained Application Protocol;MQTT,Message Queue Telemetry Transport;\
DTLS,Datagram Transport Layer Security;TCP;iBeacon;JSON;UDP" \
--startYear 2006 --savePlot "host_layers.eps"
```

RFID is the top used author's keyword in the analyzed data set and the most used media layer communication protocol in the authors' research. On IoT 923 publications are related to RFID, where security authentication [153–155], wireless sensors networks [156,157], privacy [158,159], and electronic product code (ECP) [160,161] were major applications. Next, 6LoWPAN appears in 230 publications, with documents related to upper layer protocols such as Constrained Application Protocol (CoAP) [162,163], Routing Protocol for Low power and Lossy Networks (RPL) [164,165], and operating systems like Contiki [166,167], and Android [168,169]. With similar growth, ZigBee follows with 222 documents, and research integrates this protocol with solutions such as RFID [170–172], or applications like smart home [95,173,174], and health care [175–177].

Bluetooth Low Energy (BLE) has experienced a rapid growth in the last three years, near 100% from 2015 to 2016. A total of 98 documents on IoT are related to BLE, with one of the most cited articles by Gomez et al. at 176 citations. In this article, the authors describe the main features and potential applications for BLE technology [178]. This data set shows BLE related applications such as home automation [179–181] and indoor location [182–184] and health care [185–187]. WiFi is the other network protocol used for IoT research, with a total of 85 publications, and applications related to: home automation [188,189], indoor localization [190]. Nevertheless, with this wireless technology, some authors have focused on how the 2.4 GHz spectrum could be efficiently used with other IoT network protocols [191–197]. Similarly, 5th generation mobile networks (5G) appear in IoT with 82 publications, much more than 4G and LTE, with 54 documents both combined. The most cited paper is a suvery on 5G architecture and emerging technologies written by Gupta et al. [198] with 109 citations. Network Function Visualization (NFV) and Software Defined Networking (SDN) [199–201] were the top related technologies, which offer different architectural options to address IoT needs for 5G. Finally, RPL is discussed as an IPv6 Routing Protocol for Low-Power and Lossy Networks as a mechanism for multipoint-to-point and point-to-multipoint traffic for these kinds of networks [202]. This protocol has 78 documents with publications related to the Contiki OS and its simulator tool Cooja for WSN [203,204], and mesh networks [205–207].

At the host layer, communication protocols publications are led by the Constrained Application Protocol (CoAP), which is a specialized web transfer protocol for use with constrained nodes and constrained networks [208]. A total of 201 publications were found in this area, with some of these publications related to: 6LoWPAN [163,165,209], and Datagram Transport Layer Security (DTLS) [210,211]. Second, the Message Queue Telemetry Transport (MQTT) shows up with 46 documents. This is a lightweight, and open client-server publish/subscribe messaging transport protocol [212]. Next, Datagram Transport Layer Security (DTLS) protocol follows this list with 35 publications. This DTLS provides communications privacy for datagram protocols based on the stream-oriented Transport Layer Security (TLS) [213]. This protocol helps to enhance the security of others' higher layers protocols like CoAP [214,215]. Finally, iBeacon is the fifth on this list with nine documents. This is a protocol designed by Apple (Cupertino, CA, United States) to describe its own implementation of BLE Beacon, which emits a signal that can be detected by any BLE enabled device within a close range [216]. Most of the applications for this protocol include indoor localization [50,217].

4.3. Software Processing Techniques

The proliferation of IoT has significantly increased the data collection and the strain it places on faster data analytics. Several software processing techniques have been researched, developed, and published. In these published documents, the various software processing techniques used were specified in the authors' keywords. Figure 7 shows the top authors' keywords for these processing techniques. Machine learning is the most popular research technique for data processing with 100 publications. This technique is used for data prediction [218,219], activity recognition [220,221], and data classification [222,223]. Next, data mining appears with 89 documents, with distributed data mining [224], and applications such as event detection [225,226] as sub-techniques.

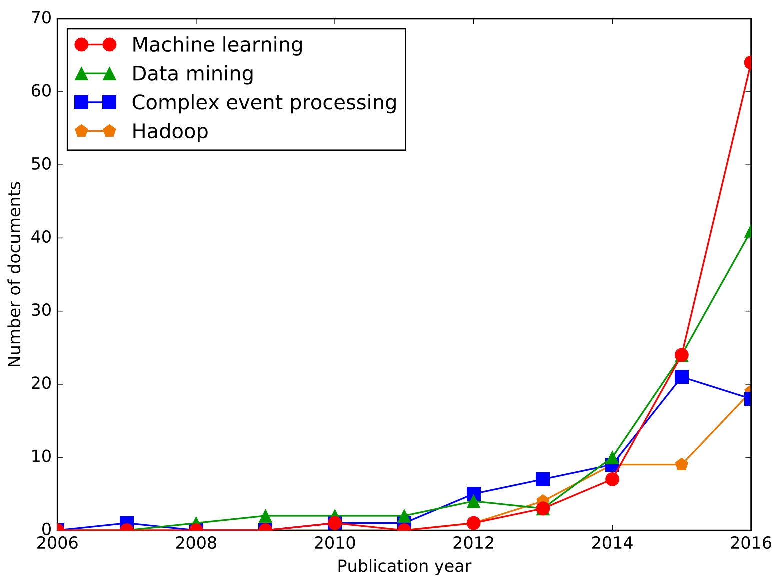


Figure 7. Internet of Things software processing techniques based on authors' keywords in documents per year, for the period 2006 to 2016.

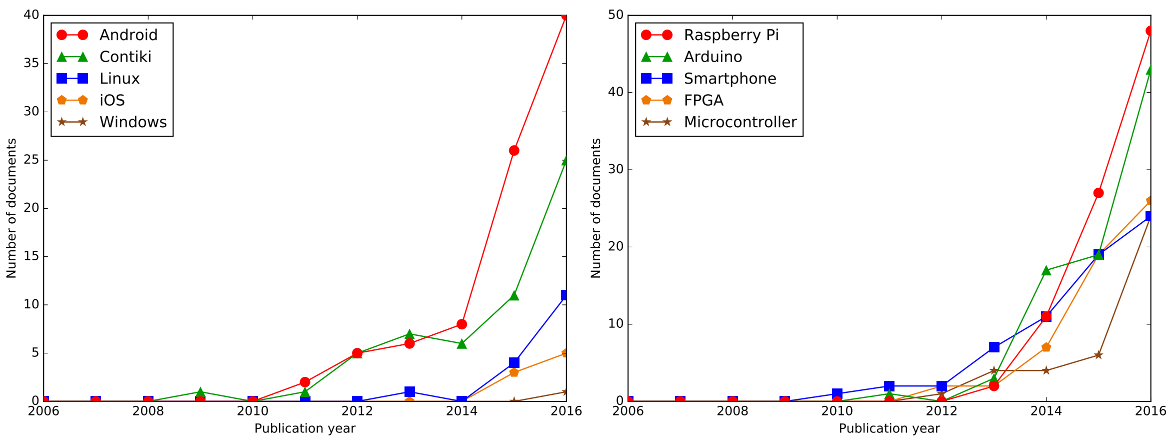
To get the previous figure, run the following script:

```
python scientoPy.py authorKeywords -t \
"Machine learning;Data mining;Complex event processing,CEP;Hadoop" \
--startYear 2006 --savePlot "software.eps"
```

Complex event processing is a method of tracking and analyzing streams of data surrounding events or anomalies and basing a conclusion from them [227]. It was found that 63 documents are related to this processing technique with applications such as supply chain [228–230] and health care [231,232]. Apache Hadoop (or Hadoop) is a software framework used for distributed storage and big data processing using the MapReduce programming model [233], appearing with 42 documents and applications including smart cities [234–236], and Social Internet of Things [237].

4.4. Device Operating Systems (OS) and Hardware

The data set analyzed here shows that the investigations used different IoT devices (end devices and gateway devices), operating systems (OS), and hardware. Figure 8 shows the top authors' keywords per year for the most employed OS and hardware. Android is the most used OS for researchers, with 87 documents. This OS is used for IoT gateways [238–241] or end sensing devices [242–244]. Contiki is a lightweight OS for memory constrained systems (like microcontroller-based systems) designed for low-power wireless devices [245]. A total of 56 publications were found related to this OS, where the author uses capabilities like embedded protocols: 6LoWPAN [166,246], CoAP [247], and RPL [248]. In addition, some publications use the Contiki network simulator Cooja to simulate routing protocols [249] and performance evaluation [250].



(**a**) (**b**)

Figure 8. Internet of Things devices operating systems (OS) and hardware based on authors' keywords, for the period 2006 to 2016. (**a**) most used operating systems in authors' keywords per year; (**b**) most used hardware in authors' keywords per year.

To get the previous figure, run the following script for operating systems:

```
python scientoPy.py authorKeywords -t \
"Android,Android OS;Contiki,Contiki OS;Linux,Linux OS;\
iOS,iPhone Operating System,iPhone Operating System (iOS);\
Windows,Windows OS" --startYear 2006 --savePlot "operating.eps"
```

To get the previous figure, run the following script for hardware:

```
python scientoPy.py authorKeywords -t \
"Raspberry Pi;Arduino,Arduino board;Smartphone,Smartphones,Smart phone,Smart phones;\
FPGA,Field-programmable gate array,Field programmable gate array;\
Microcontroller,Microcontrollers" --startYear 2006 --savePlot "hardware.eps"
```

Other operating systems, such as Linux, are used in IoT for image processing [251] and gateway services [252]. The iPhone Operating System (iOS) is used as user interface for presentation, configuration, and remote controlling for IoT environments [253]. Finally, last year, Culic et al. demonstrated the potential of Windows 10 IoT Core (Redmond, WA, United States), a light-weight version of Windows 10, as an IoT operating system optimized to run on small devices that have no display [254].

On the hardware side, some authors' keywords detail the hardware devices employed (see Figure 8b). Raspberry Pi is a small single board computer (SBC) capable of supporting operating systems like Linux Ubuntu, Windows, or Android. The Raspberry Pi is the most popular platform employed for IoT, with 88 publications, as a versatile platform for a gateway [255–257] or monitoring system [258,259]. Arduino boards are single-board microcontroller kits, in which the developer connects sensors, actuators, or RF communication interface easily using shield boards. For this specific IoT publications data set, 83 documents refer to Arduino hardware. These boards are widely used for IoT learning [253,260,261] and monitoring devices [262–264].

Presently, smartphones are highly capable embedded systems that run full OS, with integrated sensors. Sixty-six documents were found related to smartphones in IoT, be they used as sensors [265,266], gateway [267–269], or user interface [270,271]. The Field-Programmable Gate Array (FPGA) is a hardware reconfigurable component that contains an array of computational (logic) elements, with a functionality specified by a hardware description language [272]. These FPGAs are used in IoT investigations for data encryption [273–275], routing algorithms [276], and parallel simulation [277]. A microcontroller (MCU) is a small computer on a single integrated circuit, which includes a processor core, RAM/ROM memory, peripherals, and, in some cases, RF transceivers. For IoT, the MCU plays a fundamental role in sensing end devices [255,278,279] and actuators [280].

4.5. Top Trending Topics

For this analysis, the top trending topics are the authors' keywords, which have higher average growth rate (AGR) over the others. These topics represent concepts that have a large impact on IoT research. To find these trending topics, two-year AGR time periods (2011–2012, 2013–2014, and 2015–2016) were found using the following Equation (1):

$$AGR = \frac{\sum_{i=Y_s}^{Y_e} P_i - P_{i-1}}{(Y_e - Y_s) + 1}, \tag{1}$$

where:

AGR = Average growth rate;
Y_s = Start year;
Y_e = End year;
P_i = Number of publications on year i.

Figure 9 shows the top eight trending topics with the AGR time periods. Cloud computing leads, with an AGR of 90 publications/year for 2015–2016, 284 documents on 2016, and a constant growth in all time periods. In 2013, Gubbi et al. mentioned that the integration of IoT with Cloud computing applications can enable the creation of smart environments such as Smart Cities and others

[13]. The growth of publications about IoT related to Cloud computing shows that the mentioned integration is currently happening. The second trending topic on this list is security. This topic has a moderate growth in 2011–2012 and 2013–2014 periods (about 18 publications/years), but, in 2015–2016, its growth soared to 83 publications/year. Security backs the industry's concerns about the user privacy and confidentiality [281,282]. The same way that the communications protocols were analyzed in this paper by layers, Jing et al. divided the IoT into three layers (perception, transportation, and application layers) to analyze features and security issues of each [283].

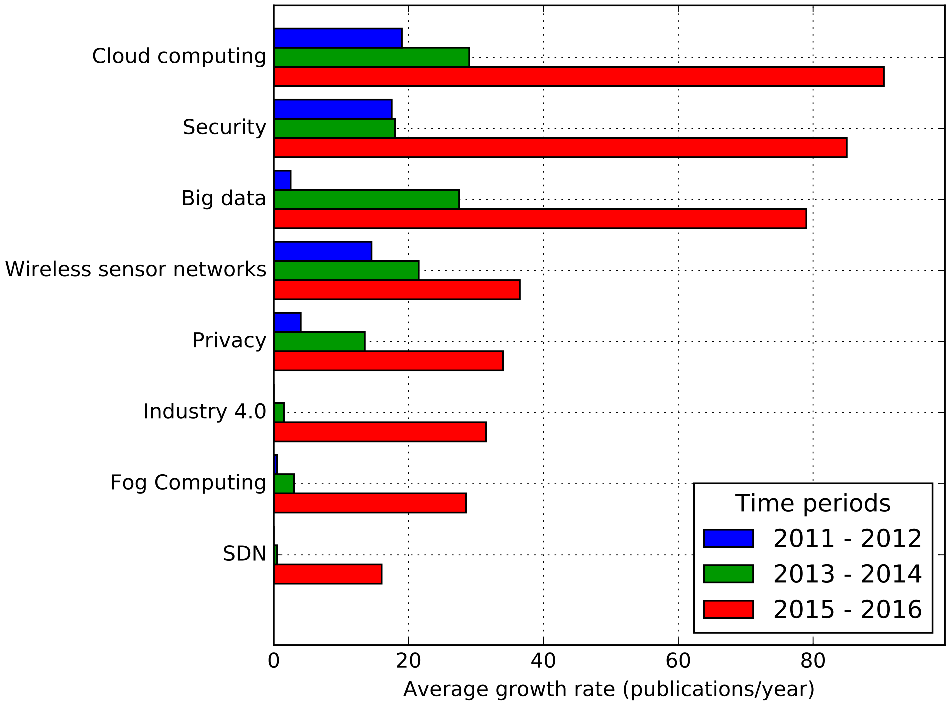


Figure 9. Internet of Things top trending topics based on authors' keywords, with average growth rate (AGR) for different times periods (2011–2012, 2013–2014, and 2015–2016).

To get the previous figure, run the following script for hardware:

```
python trendResults.py authorKeywords -t \
"Cloud computing;Security;Big Data;Wireless sensor networks;\
Privacy;Industry 4.0;Fog computing;SDN" --savePlot "trending.eps"
```

IoT is one of many applications of Big Data because the rapid growth of IoT devices further propels the sharp growth of data to be processed and analyzed [70]. Wireless sensors networks (WSN), such as RFID, is one of the most important technologies enabling the IoT [284]. Likewise, security/privacy is a trending topic and also a concern in IoT, which was well summarized in [285].

Industry 4.0 is a new trending topic, without any growth in the 2011–2012 period, but with a sharp rise in publications from 3 to 66 in 2014 to 2016. Industry 4.0 includes the use of intelligent manufacturing processes, Cyber-Physical Systems (CPSs), and implementation and operation of smart factories [286]. This fourth industrial revolution aims to integrate IoT technologies such as remote control, manufacturing analytic tools and services, supply chains integration, and tracking and tracing inter- and intra-plant logistics [287]. Fog computing is also a new trending topic, with a small growth in 2011–2014 periods, but a large increase in the 2015–2016 period. Fog is a platform that provides compute, storage and networking services between end devices and cloud computing servers, most commonly, but not exclusively, located at the edge of network [60]. For IoT, this new platform is aimed to decentralize the data processing [288], decrease the latency [289], and bring more reliability for WSN [290]. Finally, Software-Defined Networking (SDN) is a novel concept for IoT, without any growth in the 2011–2012 period, but which was gaining popularity from one publication in 2013, and 2014, to 33 in 2016. SDN brings network routing intelligence via a centralized controller that connects to the network switch through the OpenFlow protocol [291], for example. This allows efficient node mobility [292], resource management [293], and improves the security of IoT networks [291,294,295].

5. Conclusions

A scientometrics review about Internet of Things was performed over a data set of 19,035 documents published during a period of 15 years (2002–2016) from two databases (Clarivate Web of Science and Scopus). A Python script called ScientoPy was developed to make a quantitative analysis of this data set, providing insight into research trends by investigating primary author's country affiliation, most published authors, and prevalence of various research topics. Using authors' keywords, the top research topics for IoT were found, including applications, communication protocols, software processing, hardware, and operating systems.

Analysis by country affiliation of the primary author shows a major increase in the number of publications for IoT in countries where the government has possibly implemented polices that improve the development of IoT. Similarly, this increase has shown in countries where private initiatives could have launched commercial low cost IoT networks (such as LoRa, Sigfox, etc.). In addition, prototype IoT infrastructure on small test environments, such as universities, creates microcosms that foster investigations for different IoT applications.

From 2014 to 2016, there was a sharp growth of smart environments including smart city, home, grids, and other surfaces with technology incorporating Big Data and cloud computing into IoT devices. Nevertheless, security [91–93] and privacy [103,106,107] are major concerns for many applications such as smart home and grid. Cyber-Physical Systems is an application that, when powered by the IoT, enables the targets fixed by Industry 4.0 [111]. Trends in communications protocols have changed in the last few years. The RFID publications sigmoid growth is on a stationary phase, while other media layer protocols such as BLE, WiFi, and 5G are on sigmoid growth exponential phase. Host layer protocols show a high growth rate for CoAP and MQTT. Software data processing demonstrates that the techniques designed to work with Big Data are growing on the sigmoid exponential phase for IoT data processing environments.

For operating systems, Android has become the most used OS for scientific researchers on IoT. This OS has been used for IoT gateways [238–241] and user interface in IoT devices [270,271]. Contiki is growing in a sigmoid exponential phase with its integrated protocol stack and WSN simulator, Cooja. Similarly, in IoT research, Raspberry Pi and Arduino are the most popular platforms for learning and development. In addition, the combination is widely used wherein Raspberry Pi is an IoT gateway [255–257] and Arduino boards serve as edge monitoring devices [262–264]. Similarly, smartphones exhibit their versatility being used as gateway [267–269], user interface [270,271], and sensing [265,266] IoT devices. Meanwhile, FPGAs have exhibited a sigmoid exponential phase growth in the last two years, with applications such as data encryption [273–275], routing algorithms optimization [276], and parallel networks simulation [277].

Top trending topics demonstrate that cloud integration with IoT devices is enabling the implementation of smart environments. Nevertheless, security and privacy in these environments are important growing concerns for IoT researchers and industry. WSNs are one of the most utilized technologies enabling the IoT. Furthermore, Fog computing has emerged as a promising edge device to decentralize data processing, decrease latency, and bring more reliability for WSN in IoT. Likewise, research on Software Defined Networks (SDN) grew rapidly during the last year, offering more efficient nodes, mobility, resources management, and improved security of IoT networks. The related trending topics offer unique opportunities for IoT innovations and start-ups in pursuit of an efficient, secure, and reliable IoT environment.

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Conflicts of Interest: The authors declare no conflict of interest.

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