# Reviewing Recent Literature on IoT-Based System-of-Systems: A Bibliometric Analysis

Aymen Abdelmoumen[1,*], Zakaria Benzadri[1] and Ismael Bouassida Rodriguez[2]

[1]University of Constantine 2 – Abdelhamid Mehri, LIRE Laboratory, Ali Mendjeli B.P. 67A, Constantine, 25016, Algeria
[2]ReDCAD Laboratory, ENIS, University of Sfax, Tunisia

### Abstract
Emerging System-of-Systems incorporating Internet-of-Things devices is the topic of ever-increasing interest. Ranging from miniature devices (e.g., smart watch) to metropolis-wide infrastructures (e.g., smart cities), its influence is affecting our daily lives on all levels. This paper presents a bibliometric analysis focused on the integration of systems-of-systems (SoS) in Internet-of-Things (IoT) platforms. IEEExplore was the source of all the data retrieved for this study. By analyzing the relevant literature, this paper aims to provide insight into the current state-of-the-art on the integration of IoT and SoS interchangeably. Python was the main bibliometric tool used for conducting statistical analysis and visualizing the collected data. The results revealed strong correlations between groups of authors as well as co-occurrence of IoT-related terms. The data are displayed in sorted tabular form, graphs and networks for comprehensiveness and conciseness. Subsequent findings may help contribute to a better understanding of the field and inform future research directions.

### Keywords
Bibliometric Analysis, Systematic Review, IEEExplore, Internet-of-Things, Cyber-physical Systems, System-of-Systems, System-of-Systems-Engineering

## 1. Introduction

The most intuitively compatible application for systems-of-systems (SoS) is their integration within Internet of Things (IoT) platforms. This convergence facilitates the seamless integration of the adaptable and intelligent aspects of IoT devices with the high-level coordination and collective behaviors inherent in Systems-of-Systems (SoS). As a result, it has the potential to enhance overall efficiency and performance, optimize decision-making processes, elevate situational awareness, and streamline resource management [1].

However, it's worth noting that both SoS and IoT exhibit distinctive characteristics that can present intricate design and practical challenges, which may potentially hinder the full realization of their combined benefits [2]. Several well-established challenges encountered by system designers include the need to describe and manage the constant evolution of heterogeneous systems, as well as the identification of unforeseen behaviors arising from the interactions

*TACC 2023: Tunisian-Algerian Joint Conference on Applied Computing, November 6 - 8, Sousse, Tunisia*
*Corresponding author.
aymen.abdelmoumen@univ-constantine2.dz (A. Abdelmoumen); zakaria.benzadri@univ-constantine2.dz (Z. Benzadri); bouassida@redcad.org (I. Bouassida Rodriguez)
0000-0001-8177-9885 (A. Abdelmoumen); 0000-0002-5605-7415 (I. Bouassida Rodriguez)

among these systems [3]. These challenges encompass issues of interoperability, scalability, heterogeneity, complexity, and security.

Numerous approaches have been explored to tackle their inherently intricate characteristics [2] [3]. These efforts have predominantly encompassed hybrid design strategies [4] [5], pragmatic solutions [6], diverse tools and frameworks [7] [8], all aimed at bridging the divide between theory and practice. These solutions have found their way into a wide array of real-world application domains, spanning various stages of the engineering process, such as conceptual modeling [9] [10], practical design [11] [12], simulation [13] [14], post-deployment quality assessment and validation [15] [16] [17].

In this paper, we have embraced a highly systematic approach to delve into recent advancements stemming from practices and modeling techniques concerning Systems-of-Systems and the Internet-of-Things. The method we employed involves a "bibliometric analysis," akin to a survey, which entails the quantitative evaluation of the scholarly excellence of journals or authors through statistical methods and quality metrics such as citation impact, citation counts, journal rankings, h-index, and other pertinent indicators within the research domain [18] [19]. Furthermore, this analysis entails the careful selection of a suitable empirical foundation, encompassing a set of journals, authors, or publications relevant to the study.

This approach adeptly accommodates comprehensive data gathering and interpretation, ensuring the provision of insightful perspectives on the subject under investigation. Simultaneously, it evaluates impacts while mitigating potential subjective biases [20].

The structure of this paper is delineated as follows. Commencing with Section 2, we outline our preliminary plan for the research, motivating the reasoning behind our choice of tools and data sources that guide this study. This is followed by Section 3, which offers a detailed exposition of the adopted analysis methodology, offering readers a comprehensive understanding of our procedural approach. In Section 4, we present our findings, displaying the results we gathered from the specified bibliometric indicators. These results are thoroughly discussed in section 5, acknowledging any shortcomings the study suffered from. Conclusively, section 6 summarizes the findings and highlights potential directions and perspectives for future research.

## 2. Research Design

In this section, we present a summarized rundown on the strategies undertaken for realizing the outlined objectives. The adopted approach is a hybrid formulation combining conventional bibliometric methodology [21] and innovating our own. The integral process is partitioned into 2 distinct yet complementary phases; 1. ‘Research Design’ and 2. ‘Realization’, accentuating the strategic alignment between the conceptual and practical stages. This section will host the ‘design’ phase in detail. As for the ‘practical’, it will be explained in section 3. Figure 1 briefly illustrates the steps of the approach:

Each stage of this plan contributes to a coherent and impactful research study:

1. **Defining the Research Questions:** This initial step involves formulating clear and concise research questions that guide the entire bibliometric analysis [22].
2. **Selecting Data Sources:** In this phase, an appropriate data source that aligns with the context of the research is chosen.

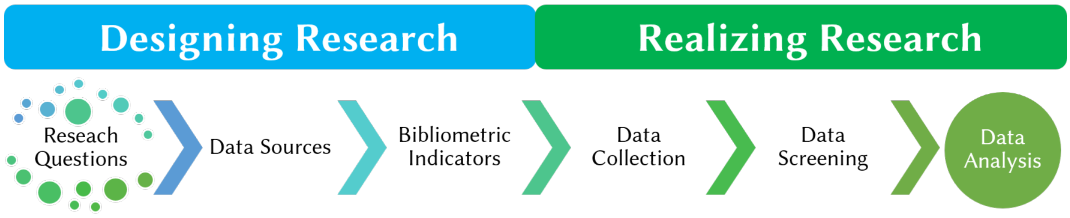


**Figure 1:** Research Design and Realization

3. **Choosing Bibliometric Indicators:** These indicators are identified and underlined early in the process as to answer to each of the analysis' objectives.
4. **Collecting Data:** this step comprises of carefully choosing the relevant keywords and retrieving back the resulting sets of data.
5. **Planning Data Filters:** Establishing a clear plan for preprocessing data is key step that involves cleaning, formatting, and organizing the collected data.
6. **Applying the Analysis:** the cornerstone of our approach is to derive insights from the collected data. This involves selecting appropriate statistical methods, data visualization techniques, and algorithms tailored to the research objectives and the chosen bibliometric indicators. (This step is separate from reporting any results [23]).

## 2.1. Research Questions

In this section of the article, we will be giving direction and purpose to our bibliometric review by enumerating specific research questions. The answer to these queries may either help solidify our pre-established assumptions about the research, or identify and revise any potential misconceptions. The subsequent analysis will be founded on answering 3 main research questions using a variety of quantitative methods:

- **RQ1:** How well does the literature fare regarding SoS and IoT in recency?
- **RQ2:** What are the most resourceful entities known to partake extensively in the enrichment of the IoT-based SoS state-of-the-art?
- **RQ3:** What fields of research are dominantly associated with IoT/SoS in recent years?
- **RQ4:** What other fields is the research on IoT shifting towards?

## 2.2. Data Sources

In regards to the topic of this study, IEEE is considered a credible and reputable publisher. IEEE journals are top ranked in the Thomson Reuters Journal Citation Reports® (JCR). Based on Scopus data, as of June 23rd, 2023, IEEE Systems Journal upholds an impact score of 5.6 and a h-index of 98 [24]. it has thus been elected as our main source of documents for bibliometric data. Its advanced command search for scientific documents is very selective and results are largely relevant to our topic, as IEEE mainly publishes Computer and Electronics-related articles. Additionally, it accurately sorts and filters results by simply ticking the corresponding boxes on the IEEEExplore webpage [25].

### 2.3. Bibliometric Indicators

The scope of this study, as the title suggests, extends to a timeframe that is deemed relatively novel for computer science research and especially relevant to IoT platforms, SoS and SoS Engineering. Therefore, it is characterized by recent and well received advancements within the domain. We intend to achieve that by ensuring that both ‘activeness’ and ‘impact’ are equally presented. Hence, we have selected pertinent bibliometric measurements including: 1. citation counts, 2. contribution frequency and 3. co-occurrence relationships of several parameters, depending on the available data. With the finalization of the research design, our next logical step would be the execution of the meticulously designed plan in this next section labeled ‘methodology’.

## 3. Methodology

This section serves as a strict elaboration on the ‘realization’ phase previously mentioned in the schema (figure 1). We outlined the steps undertaken to collect, process and organize the data, utilizing Python as our primary tool throughout the procedure.

### 3.1. Data Collection

To initiate the data collection process as a first step, we have collected recent publications related to IoT, CPS, SoS, and SoS Engineering. Our search began in July 10th, 2023 on the “`IEEExplore`” indexing database. The chosen terms are deemed relevant and align with the objectives of our research. The following command was executed via the advanced command tab:

```
(system*of?systems OR SoS OR system*of?systems?engineering OR SoSE)
AND (internet?of?things OR IoT OR cyber?physical?systems OR CPS)
```

In addition to this, only IEEE Journal publications from 2018 until 2023 were considered. These filters were applied for novelty and pertinence in accordance to the scope of this paper. The search was done at exactly: 10:53 am. Due to the large volume of results (7032 paper), they were sorted by ‘Most Cited by Papers’ and exported to a limit of 2000, and were then retained in a .csv file. Another search with identical parameters was initiated at 11:05 am. However, this time, the resulting papers were exported based on “Relevance”. Likewise, the first 2000 documents were retained in .csv format. The documents’ metadata include: Title, Authors, Author Affiliations, Publication Title (Journal), Publication Year, DOI, PDF Link, Article Citation Count, Reference Count, Author Keywords, IEEE Terms, INSPEC Controlled Terms and Non-Controlled Terms. Two queries were performed for the purpose of optimizing data quality, as only papers that are extensively cited by other papers and also highly relevant to the specified search query are included in the results.

### 3.2. Data Processing

The two sets of data were downloaded, then merged and saved in a separate file, subsequently undergoing a check for duplicates. The processing was done through a python script. Duplicates were retained on the basis of "`Document Title`" and "`DOI`"; resulting in the removal of 2598 distinct entry, meaning that duplicate entries sum up to 1402. By retaining one record of each duplicate, the processed dataset then contained information on a maximum of 701 papers.

Figure 2 summarizes the data collection process and the preprocessing done to the dataset for the upcoming analysis:

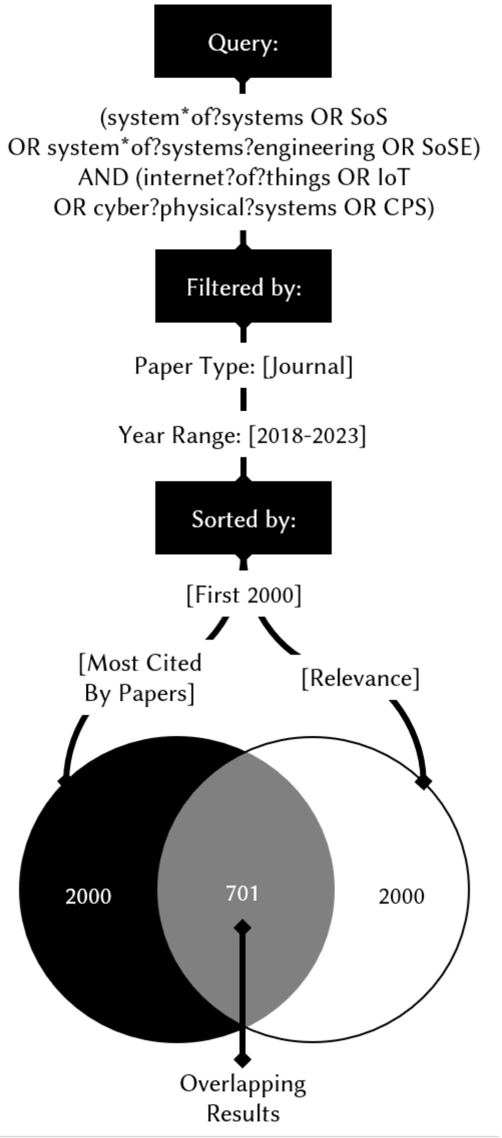


**Figure 2:** Summary of Data Collection and Preprocessing of IEEExplore results

### 3.3. Data Analysis

Python was instrumental in conducting the analysis by taking collected data as input and employing various libraries and functions to derive meaningful statistics and extract relevant bibliometric indicators. Furthermore, its capabilities to output graphical data allowing us to visualize the results and facilitating its comprehension and interpretation. We employed a number of analytics regarding authorship, geographic distribution, institutional contributions, keyword occurrence and co-mapping. Of which we cite the following:

- **Publications:** the initial step was to present superficial data on the search. 2 key analyses were done; **(i.)** publication frequency over time, and **(ii.)** impactful papers marked by a relatively high number of citations.
- **Authors:** regarding this analysis, we have employed a variety of algorithms for retrieving significant bibliometric data. First off, we were able to sort the authors with most contributions overall, as well as most contributions as a first author. We have also mapped them to the number of citations of their respective contributions. For visual comparison, we drew a bar chart for each author. The bars correspond respectively to the number of citations as a first author and the overall number of contributions. Additionnally, we have drawn a series of co-authorship graphs for most influencial authors only.
- **Keywords:** As for keyword occurrence. A number of measures were taken. Firstly, the initial dataset provides 4 types of key terms:

    1. Author-defined keywords
    2. IEEE assigned terms
    3. INSPEC Non-Controlled terms
    4. INSPEC Controlled terms

  `"Author keywords"` were discarded for highly common cases of redundancy. There is no clear standard as to how some keywords are spelled and therefore we were left with different names for identical concepts (e.g. *internetofthings*, *internet-of-things*, *IoT...*) `"IEEE terms"` however, are distinct, and that helped us identify them individually for further analysis. For this instance, we applied a similar process to draw a multitude of co-occurrence graphs. The graphs only contains keywords cited in great numbers. `"INSPEC Controlled"` and `"Non-Controlled Terms"` were also discarded as, in programming terms, additional processing was required in order to identify the topic of given records. Besides, their IEEE assigned counterparts were already available.
- **Countries:** this subsection sets the spotlight on the contributability and influence of each country mentioned in the results of the search by countries on the basis of **(i.)** number of papers published and **(ii.)** number of citations per published article. Both of which were projected on a pie chart.
- **Institutes:** in a much similar manner, this analysis simply highlights the most active institutes and the most cited ones throughout the search.

# 4. Findings

## 4.1. General analysis

**Activity in Recent Years:** the graph in figure 3 presents the number of articles published for each year in the span of these past 5 years (including '2023', the year in which the search was done) concerning the 701 publications in the dataset.

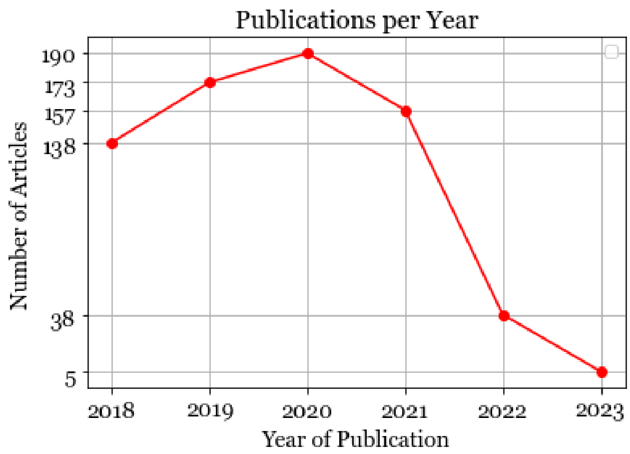


**Figure 3:** Number of Articles Over the Years

As shown in the graph (figure 3), it turns out the number of publications regarding our topic is in decline as compared reflexively. This might be due to the nature of the search which selectively excluded all papers that are yet to be published (early-access), and as all these papers are journal articles, the publishing process can take a considerable amount of time.

**Influential Publications:** among 701 records in the dataset, Table 1 showcases the first 10 most cited articles that are relevant to the topic mentioned in the command query:

**Table 1**
Citations per Publication

| Rank | Reference | Citations |
|---|---|---|
| 1 | [26] | 654 |
| 2 | [27] | 651 |
| 3 | [28] | 631 |
| 4 | [29] | 630 |
| 5 | [30] | 467 |
| 6 | [31] | 448 |
| 7 | [32] | 433 |
| 8 | [33] | 419 |
| 9 | [34] | 373 |
| 10 | [35] | 371 |

### 4.2. Authorship analysis

**Most Contributing Authors:** Table 2 highlights the most active authors in terms of contribution count. The middle-right column indicates the number of times the author is mentioned in published articles regardless of how they contributed in it. On the right-most column, it is shown how many of those mentions correspond to a main authorship. 2396 individual researcher who have contributed in at least one article is present in this dataset. We considered 'most first authorships' as a criterion for sorting these results:

**Table 2**
Contributions per Author

| Rank | Author's name | Contributions | as First |
|---|---|---|---|
| 1 | Y. Zhang | 18 | 5 |
| 2 | G. Fortino | 6 | 4 |
| 3 | M. Abdel-Basset | 5 | 4 |
| 4 | Y. Li | 12 | 3 |
| - | X. Liu | 12 | 3 |
| 6 | J. Wang | 11 | 3 |
| 7 | G. Yang | 8 | 3 |
| - | J. Li | 8 | 3 |
| 9 | Y. Xu | 7 | 3 |
| - | X. Li | 7 | 3 |

**Most Cited Authors:** Moreover, after having mapped all authors to their contributions, we extracted the number of citations for each one in correspondence to the number of citations of their respective papers. Here are the 10 most cited scholars:

**Table 3**
Contributions per Author

| Rank | Author's name | Citations | Contributions |
|---|---|---|---|
| 1 | Y. Zhang | 867 | 18 |
| 2 | K. K. R. Choo | 818 | 14 |
| 3 | T. Taleb | 753 | 3 |
| 4 | N. Moustafa | 728 | 7 |
| 5 | B. Sikdar | 689 | 2 |
| 6 | V. Chamola | 676 | 2 |
| 7 | R. H. Glitho | 665 | 2 |
| - | C. Mouradian | 665 | 2 |
| 9 | R. Bera | 654 | 1 |
| - | L. Chettri | 654 | 1 |

To give these numbers more significance, we employed the '`matplotlib`' library in python to generate a bar chart containing 2 super-imposed bars for each author; the blue one representing their overall number of contributions, and the green one representing only the ones as a first author. This helps illustrate a clear comparative view of the most influential authors and the number of contributions as first author or otherwise. The results were sorted by number of citations and the first 50 were selected for display in figure 4:

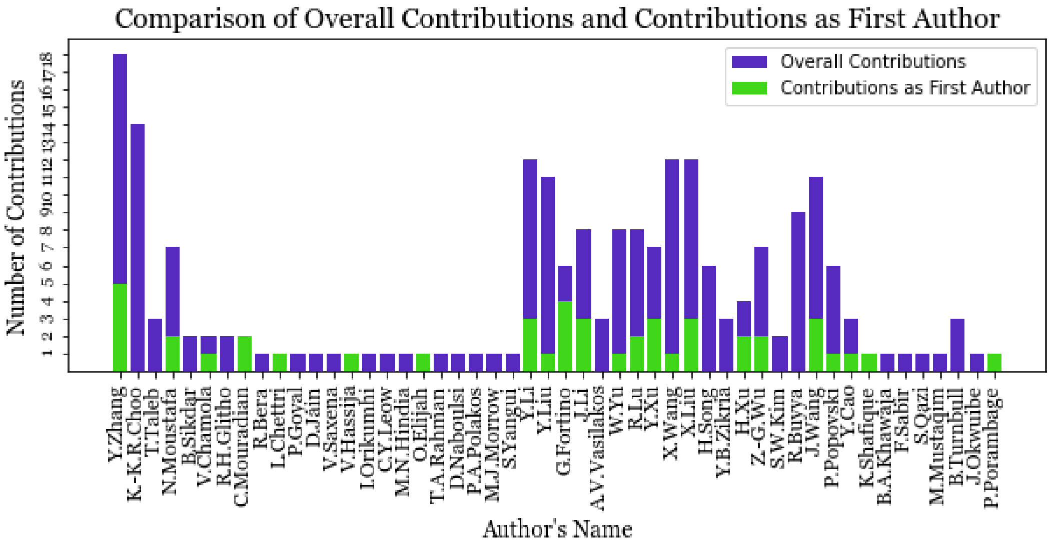


**Figure 4:** Overall and First Author Contributions of Top 20 Most Cited Authors

**Co-authorship:** The `'networkx'` python library allowed for the systematic representation of authors as nodes and co-author relationships as edges in the graph. By leveraging the library's functions, 3 networks were meticulously crafted to reflect the connections between the most influencial authors and their co-authors; end results displayed in Figure 5. The separation of each author apart was done so to enhance to the clarity of the analysis. By isolating each significant author, the resulting networks provide a focused and manageable view of their co-author reltationships, thereby facilitating its interpretation:

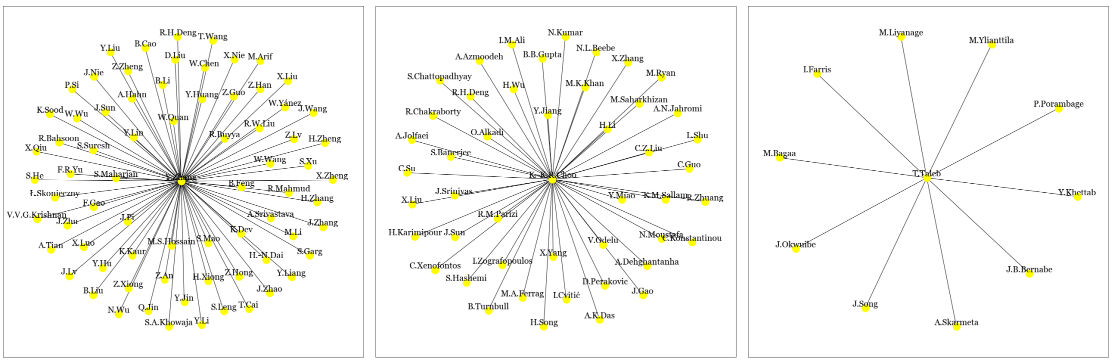

**Figure 5:** Co-authorship network for authors 'Y. Zhang', 'K. K. R. Choo' and 'T. Taleb' respectively

### 4.3. Keyword Analysis

**Most Mentioned Keywords:** We have identified 854 distinct keywords regarding the column '`IEEE Terms`' in the source dataset. As it was mentioned before, "`Author Keywords`" are not subject to this analysis, for reasons such as inconsistency and redundancy.

**Table 4**
Occurrences per Keyword

| Rank | Keyword | Occurrences |
|---|---|---|
| 1 | Internet of Things | 393 |
| 2 | Cloud Computing | 127 |
| 3 | Security | 114 |
| 4 | Sensors | 90 |
| 5 | Wireless Sensor Networks | 76 |
| 6 | Monitoring | 75 |
| 7 | Protocols | 72 |
| - | Real-Time systems | 72 |
| 9 | Servers | 70 |
| 10 | Task analysis | 68 |

**Keywords per Year:** In this analysis, we were aiming to grasp insight on the shift of interest in topics related to IoT through categorizing keyword frequency by year. It turns out, logically, '`Internet of Things`' is the most recurring keyword. It was omitted from this analysis because we are trying to highlight what other keywords are associated with it. The years '2022' and '2023' were not considered as there were too few samples to build a meaningful viewpoint (38 and 5 publications, respectively). Table 5 shows the obtained results:

**Table 5**
Keyword Occurrence per Year

| Keyword | 2018 | 2019 | 2020 | 2021 |
|---|---|---|---|---|
| Cloud Computing | 25 | 29 | 36 | 30 |
| Security | 9 | 27 | 31 | 36 |
| Sensors | 25 | 20 | 19 | 27 |
| Wireless Sensor Networks | 20 | 21 | 15 | 19 |
| Wireless communication | 16 | 15 | 24 | 12 |
| Edge computing | 17 | 12 | 24 | 13 |
| Monitoring | 15 | 25 | 19 | 17 |
| Protocols | 15 | 21 | 21 | 15 |
| Real-Time systems | 19 | 19 | 14 | 17 |
| Servers | 7 | 14 | 23 | 22 |
| Task analysis | 8 | 9 | 23 | 26 |

**Co-occurrence:** through a process analog to the one employed for establishing co-authorship networks, we were able to plot the 3 most mentioned keywords on a network graph each. To avoid complexity and intra-convolutedness, only keywords having occurred for more than 5 times together were assigned a link in-between. and a node was placed for each keyword, as in Figure 6:

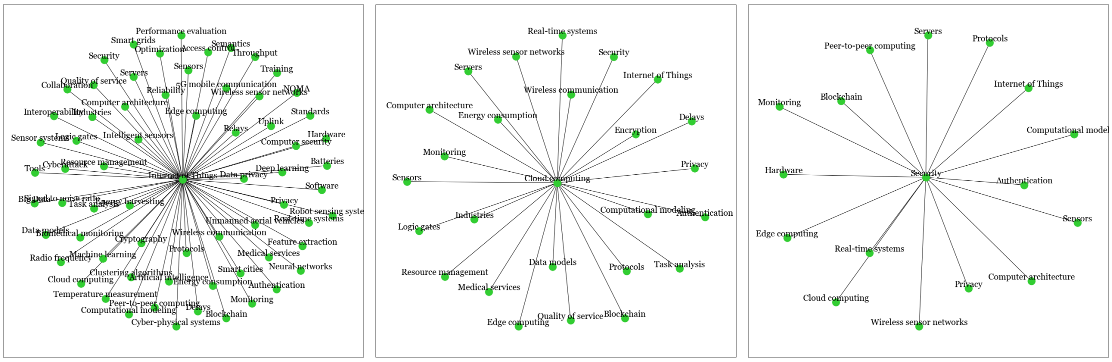


**Figure 6:** Co-authorship network for keywords 'Internet of Things', 'Cloud computing' and 'Security' respectively

## 4.4. Affiliation Analysis

**Most Contributions by Country:** After analyzing the number of contributions by each country, 90 countries were initially deduced from the results. However, upon manual inspection, there seemed to have been some confusion in a few entries, for example, some articles were listed as 'United Arab Emirates' and others under the abbreviated label 'UAE', other examples include 'USA' and 'US', 'China' and 'R.O.C', 'Republic of Korea' and 'South Korea'. Some other papers were published under their 2-letter country code (i.e., DK and Denmark, CA and Canada). These entries were merged and then ranked as in Table 6:

**Table 6**
Contributions per Country

| Rank | Country | Contributions | Citations |
|---|---|---|---|
| 1 | China | 804 | 38883 |
| 2 | USA | 407 | 22465 |
| 3 | Australia | 226 | 12191 |
| 7 | U.K. | 153 | 9799 |
| 4 | India | 140 | 10573 |
| 5 | Canada | 134 | 9224 |
| 6 | South Korea | 125 | 9116 |
| 9 | Italy | 117 | 5910 |
| 9 | Spain | 95 | 4335 |
| 10 | Pakistan | 87 | 5578 |

Using the python module '`matplotlib`', we were able to draw the following pie chart (Figure 7) to put into perspective a wider range of the results, displaying the top 20 countries by percentage of contributions:

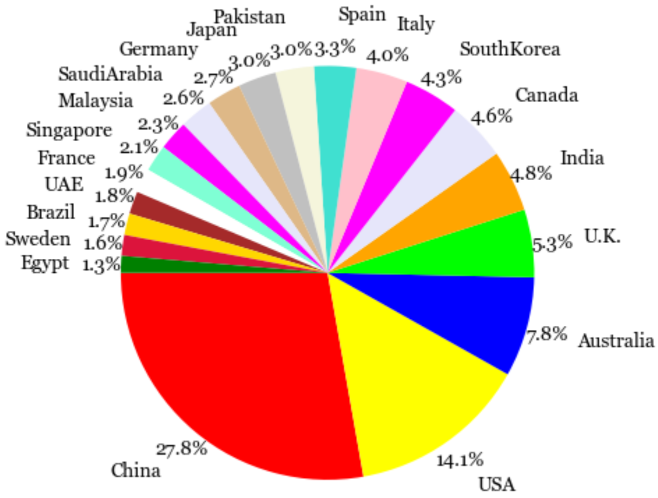


**Figure 7:** Distribution of Contributions by Country

**Most Citations by Country:** By sorting the previous results in terms of overall citation count, the ranking of the top countries somewhat changed, as the tabular data (Table 7) suggests:

**Table 7**
Citations per Country

| Rank | Country | Contributions | Citations |
|---|---|---|---|
| 1 | China | 804 | 38883 |
| 2 | USA | 407 | 22465 |
| 3 | Australia | 226 | 12191 |
| 4 | India | 140 | 10573 |
| 5 | U.K. | 153 | 9799 |
| 6 | Canada | 134 | 9224 |
| 7 | South Korea | 125 | 9116 |
| 8 | Malaysia | 67 | 5980 |
| 9 | Italy | 117 | 5910 |
| 10 | Pakistan | 87 | 5578 |

Figure 8 shows 20 entries instead of just 10, illustrating an expanded portion of the data:

**Most Mentioned Institutes:** the organizations to which authors are affiliated were extracted and ordered by number of contributions. A maximum of 1647 different institute (laboratories, universities, research centers) was obtained and is shown in (Table 8) along with the number of times assuming position of main (first) contributor:

**Most Cited Institutes:** similarly, the output holds information on 1647 records, however, their ranking differs as some institutes have made valuable contributions with less articles published, and others have published more but without considerable impact. The analysis in Table 9 is more significant in identifying the value of the contributions by said institutes, contrary to previous results which simply reflect the activity of institutes in recent years.

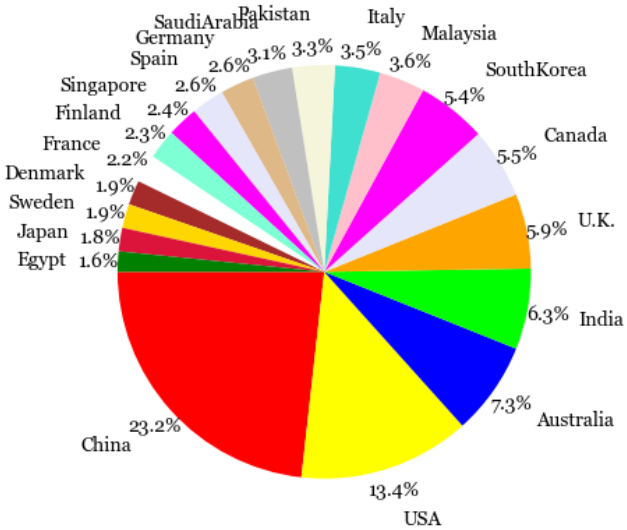


**Figure 8:** Percentage of Citation Count Shared by Each Country

**Table 8**
Contributions per Institute

| Rank | Institution's name | Contributions | Main |
|---|---|---|---|
| 1 | Center for Innovative Integrated Electronic Systems, Tohoku University, Sendai, Japan | 26 | 0 |
| 2 | Department of Information Systems and Technology, Mid Sweden University, Sundsvall, Sweden | 23 | 21 |
| 3 | Department of Electronic Systems, Aalborg University, Aalborg, Denmark | 18 | 17 |
| 4 | Institute for Communication Systems, University of Surrey, Guildford, U.K. | 17 | 9 |
| 5 | Department of Computer and Information Sciences, Towson University, Towson, MD, USA | 16 | 16 |
| 6 | School of Computer Science and Engineering, Nanyang Technological University, Singapore | 15 | 10 |
| 7 | School of Electrical and Electronic Engineering, Yonsei University, Seoul, South Korea | 14 | 14 |
| 8 | Department of Information Engineering, University of Brescia, Brescia, Italy | 14 | 10 |
| 9 | Department of Electrical and Computer Systems Engineering, Monash University, Melbourne, VIC, Australia | 13 | 13 |
| 10 | Department of Systems and Computer Engineering, Carleton University, Ottawa, ON, Canada | 12 | 10 |

**Table 9**
Citations per Institute

| Rank | Institution's name | Citations | Contributions |
|---|---|---|---|
| 1 | Concordia Institute for Information Systems Engineering, Concordia University, Montreal, QC, Canada | 2802 | 12 |
| 2 | Department of CSE and IT, Jaypee Institute of Information Technology, Noida, India | 2604 | 4 |
| 3 | Department of Electronic Systems, Aalborg University, Aalborg, Denmark | 2189 | 18 |
| 4 | Department of Information and Communication Engineering, Yeungnam University, Gyeongsan, South Korea | 2008 | 8 |
| 5 | Wireless Communication Center, Universiti Teknologi Malaysia, Johor Bahru, Malaysia | 1893 | 3 |
| 6 | Center for Wireless Communications, University of Oulu, Oulu, Finland | 1792 | 4 |
| 7 | Real-Time Power and Intelligent Systems Laboratory, Clemson University, Clemson, SC, USA | 1464 | 4 |
| 8 | Department of Information Systems and Technology, Mid Sweden University, Sundsvall, Sweden | 1328 | 23 |
| 9 | 5G IoT Lab, Sikkim Manipal Institute of Technology, Sikkim Manipal University, Majitar, India | 1308 | 2 |
| 10 | Office of the CTO, CISCO Systems, Inc., San Jose, CA, USA | 1260 | 2 |

# 5. Discussion

## 5.1. Results

The research questions raised in section 2 have found their answers through the findings we've gathered. In this section we've mapped each question to its answer:

**RQ1:** *"How well does the literature fare regarding SoS and IoT in recency?"*
**A1:** we can fairly say that there is ample interest if we consider publication frequency for a metric, the preliminary results show 7032 publication in total before applying any filters and data preprocessing. The number of citations per article shown in Table 1 is admirable for such recently published articles.

**RQ2:** *"What are the most resourceful entities known to partake extensively in the enrichment of the IoT-based SoS state-of-the-art?"*
**A2:** The findings of this study shed light on key players shaping the state of the literature concerning Iot and SoS. By observing the data in sections 4.2. and 4.4., we can deduce a number of things. Namely, influential authors and institutions are identified in tables 2, 3, 8, and 9, as well as distribution by countries, shown in tables 5, 6 and figures 7, 8. Collaboration networks (Figure 5) also help significantly in providing valuable insight on the leading actors of this interdisciplinary field.

**RQ3:** *"What fields of research are dominantly associated with IoT/SoS in recent years?"*
**A3:** the study unveils the intersection of IoT and SoS with various other fields. Tables 4 and 5

present the most common keywords associated with IoT and their popularity through the years. The networks in Figure 6 offer a clear perspective on the confluence taking place between these research domains.

**RQ4:** *"What other fields is the research on IoT shifting towards?"*
**A4:** There are entries in Table 5 that exhibit a gradual rise in interest across the years. The most prominent fluctuations can be observed in the following keywords; `"Security"`, `"Servers"` and `"Task analysis"`. It is, cordially, assumed that IoT research is progressively leaning in the direction of said topics.

### 5.2. Limitations

Throughout the process, several obstacles have effectively hindered the quality of the final results. We recognize a series of limitations inherent in the chosen scope and used tools. First, we were constrained by the quantity of preliminary data to work on. 701 sample is not a terrible number by any means; however, it is not great in any sense either.

Secondly, the choice of data sources was limited on a singular database (ieeexplore). That posed a decrease in the quality of the data. For example, the data downloaded from ieeexplore comprises of exactly 1 mention of 'systems of systems' in the 'IEEE Terms' column despite the command query clearly stating it with the corresponding wildcards to avoid syntactic confusion. That could be due to the SoS-related papers either being deemed irrelevant by the sorting algorithm on the website, or for having very little popularity and therefore not making it in the top 2000.

Lastly, the plotted graphs, especially the networks, greatly undermine the analysis. They only show a fraction of the data and in a very simplified manner so as to match human readability standards.

## 6. Conclusion

SoS and IoT have been the of subject to ever-expanding surge of interest in the last decade. The sheer diversity of real-world applications stemming from them are so diverse that a conventional narrative literature review could hardly encompass all the concepts anchored to the overarching themes of SoS or IoT.

In recognition of this, our bibliometric analysis is distinctly focused on the recent history of IoT-related publications. Leveraging the capabilities of the Python programming language and its accompanying libraries proved handy in extracting, processing, analyzing and plotting raw data in a multifaceted manner. We were able to transform the retrieved data, along structured tables and labeled graphs, into a visual narrative that encompasses pie charts, bar charts and network graphs that unveil meaningful patterns and relationships of co-occurrence and collaborations between authors.

Given the promising relevance of SoS and IoT, we encourage authors to persist in their exploration of this field. Moreover, we incite on the combination of adjacent and complementary modeling approaches such as Digital Twin technology, Deep Learning, and the emerging landscape of Quantum Computing. The intertwining of these domains could potentially unravel great things in the future.

## Acknowledgment

This work was partially supported by the LABEX-TA project MeFoGL: "Méthode Formelles pour le Génie Logiciel"

## References

[1] F. Alkhabbas, R. Spalazzese, P. Davidsson, Iot-based systems of systems, Proceedings of the 2nd edition of Swedish Workshop on the Engineering of Systems of Systems (SWESoS2016) (2016) 34–37.

[2] G. Fortino, C. Savaglio, G. Spezzano, M. Zhou, Internet of things as system of systems: A review of methodologies, frameworks, platforms, and tools, IEEE Transactions on Systems, Man, and Cybernetics: Systems 51 (2021) 223–236. doi:10.1109/tsmc.2020.3042898.

[3] B. Lebtag, P. Teixeira, V. G. Neto, A systematic mapping on executable models for the architectural design of systems-of-systems, Anais do IV Workshop em Modelagem e Simulação de Sistemas Intensivos em Software (2022) 11–20. doi:10.5753/mssis.2022.225662.

[4] A. Seghiri, F. Belala, N. Hameurlain, A formal language for modelling and verifying systems-of-systems software architectures, International Journal of Systems and Service-Oriented Engineering 12 (2022) 1–17. doi:10.4018/IJSSOE.297137.

[5] J. Delsing, G. Kulcsár, O. Haugen, Sysml modeling of service-oriented system-of-systems, Innovations Syst Softw Eng (2022). doi:10.1007/s11334-022-00455-5.

[6] B. Karaduman, M. Challenger, Smart cyber-physical system-of-systems using intelligent agents and mas, in: Engineering Multi-Agent Systems, volume 13190, Springer, Cham, 2021. doi:10.1007/978-3-030-97457-2_11.

[7] Y. Nomaguchi, K. Fujita, A framework of system of systems design with scenario, multi-agent simulation and robustness, Procedia CIRP 60 (2017) 133–138. doi:10.1016/j.procir.2017.01.008.

[8] S. K. R. Harbo, E. P. Voldby, J. Madsen, M. Albano, A diagram-centric modeling tool for systems of systems, Proceedings of the 25th International Conference on Model Driven Engineering Languages and Systems: Companion Proceedings (MODELS '22) (2022) 51–55. doi:10.1145/3550356.3559093.

[9] A. Gassara, I. B. Rodriguez, M. Jmaiel, A tool for modeling sos architectures using bigraphs, Proceedings of the Symposium on Applied Computing (SAC '17) (2017) 1787–1792. doi:10.1145/3019612.3019802.

[10] I. G. Vargas, T. Gottardi, R. T. V. Braga, An approach to integrate systems towards a directed system-of-systems, Proceedings of the 12th European Conference on Software Architecture: Companion Proceedings (ECSA '18) (2018) 1–7. doi:10.1145/3241403.3241431.

[11] M. Chaabane, I. B. Rodriguez, R. Colomo-Palacios, W. Gaaloul, M. Jmaiel, A modeling approach for systems-of-systems by adapting iso/iec/ieee 42010 standard evaluated by goal-question-metric, Sci. Comput. Program. 184 (2019). doi:10.1016/j.scico.2019.102305.

[12] N. Akhtar, S. Hussain, Formal modelling of a mail transport system based on multi-agent system of systems, Journal of Information Communication Technologies and Robotic Applications 10 (2019) 68–79.
[13] A. Gassara, I. B. Rodriguez, M. Jmaiel, K. Drira, Executing bigraphical reactive systems, Discrete Applied Mathematics 253 (2019) 73–92. doi:10.1016/j.dam.2018.07.006.
[14] W. Manzano, V. V. G. Neto, E. Y. Nakagawa, Dynamic-sos: An approach for the simulation of systems-of-systems dynamic architectures, The Computer Journal 63 (2020) 709–731. doi:10.1093/comjnl/bxz028.
[15] A. Gassara, I. B. Rodriguez, M. Jmaiel, K. Drira, A bigraphical multi-scale modeling methodology for system of systems, Computers & Electrical Engineering 58 (2017) 113–125. doi:10.1016/j.compeleceng.2017.01.016.
[16] F. Lonetti, V. O. Neves, A. Bertolino, Designing and testing systems of systems: From variability models to test cases passing through desirability assessment, Journal of Software: Evolution and Process 34 (2022). doi:10.1002/smr.2427.
[17] K. A. Raz, P. C. Wood, L. Mockus, D. A. Laurentis, System of systems uncertainty quantification using machine learning techniques with smart grid application, Systems Engineering 23 (2020) 770–782. doi:10.1002/sys.21561.
[18] G. Ahamer, K. A. Kumpfmüller, Education and literature for development in responsibility: Partnership hedges globalization, in: Handbook of Research on Transnational Higher Education, IGI Global, 2014, pp. 526–584. doi:10.4018/978-1-4666-4458-8.ch027.
[19] E. Ahmad, Model-based system engineering of the internet of things: A bibliometric literature analysis, IEEE Access 11 (2023) 50642–50658. doi:10.1109/ACCESS.2023.3277429.
[20] O. Ellegaard, J. A. Wallin, The bibliometric analysis of scholarly production: How great is the impact?, Scientometrics 105 (2015) 1809–1831. doi:10.1007/s11192-015-1645-z.
[21] N. Donthu, S. Kumar, D. Mukherjee, N. Pandey, W. M. Lim, How to conduct a bibliometric analysis: An overview and guidelines, Journal of Business Research 133 (2021) 285–296. doi:10.1016/j.jbusres.2021.04.070.
[22] K. Mattick, J. Johnston, A. de la Croix, How to…write a good research question, Clin Teach 15 (2018) 104–108. doi:10.1111/tct.12776.
[23] I. Zupic, T. Čater, Bibliometric methods in management and organization, Organizational Research Methods 18 (2015) 429–472. doi:10.1177/1094428114562629.
[24] Resurchify.com, Ieee access, 2023. URL: https://www.resurchify.com/impact/details/11300153734#:~:text=The%20overall%20rank%20of%20IEEE,this%20journal%20is%20ranked%201.448.
[25] Ieee xplore, 2023. URL: https://ieeexplore.ieee.org/Xplore/home.jsp.
[26] L. Chettri, R. Bera, A comprehensive survey on internet of things (iot) toward 5g wireless systems, IEEE Internet of Things Journal 7 (2020) 16–32. doi:10.1109/JIOT.2019.2948888.
[27] V. Hassija, V. Chamola, V. Saxena, D. Jain, P. Goyal, B. Sikdar, A survey on iot security: Application areas, security threats, and solution architectures, IEEE Access 7 (2019) 82721–82743. doi:10.1109/ACCESS.2019.2924045.
[28] O. Elijah, T. A. Rahman, I. Orikumhi, C. Y. Leow, M. N. Hindia, An overview of internet of things (iot) and data analytics in agriculture: Benefits and challenges, IEEE Internet of

Things Journal 5 (2018) 3758–3773. doi:10.1109/JIOT.2018.2844296.
[29] C. Mouradian, D. Naboulsi, S. Yangui, R. H. Glitho, M. J. Morrow, P. A. Polakos, A comprehensive survey on fog computing: State-of-the-art and research challenges, IEEE Communications Surveys & Tutorials 20 (2018) 416–464. doi:10.1109/COMST.2017.2771153.
[30] K. Shafique, B. A. Khawaja, F. Sabir, S. Qazi, M. Mustaqim, Internet of things (iot) for next-generation smart systems: A review of current challenges, future trends and prospects for emerging 5g-iot scenarios, IEEE Access 8 (2020) 23022–23040. doi:10.1109/ACCESS.2020.2970118.
[31] P. Porambage, J. Okwuibe, M. Liyanage, M. Ylianttila, T. Taleb, Survey on multi-access edge computing for internet of things realization, IEEE Communications Surveys & Tutorials 20 (2018) 2961–2991. doi:10.1109/COMST.2018.2849509.
[32] S. Kuutti, S. Fallah, K. Katsaros, M. Dianati, F. Mccullough, A. Mouzakitis, A survey of the state-of-the-art localization techniques and their potentials for autonomous vehicle applications, IEEE Internet of Things Journal 5 (2018) 829–846. doi:10.1109/JIOT.2018.2812300.
[33] M. Ayaz, M. Ammad-Uddin, Z. Sharif, A. Mansour, E.-H. M. Aggoune, Internet-of-things (iot)-based smart agriculture: Toward making the fields talk, IEEE Access 7 (2019) 129551–129583. doi:10.1109/ACCESS.2019.2932609.
[34] M. Elhoseny, G. Ramírez-González, O. M. Abu-Elnasr, S. A. Shawkat, N. Arunkumar, A. Farouk, Secure medical data transmission model for iot-based healthcare systems, IEEE Access 6 (2018) 20596–20608. doi:10.1109/ACCESS.2018.2817615.
[35] Y. A. Qadri, A. Nauman, Y. B. Zikria, A. V. Vasilakos, S. W. Kim, The future of healthcare internet of things: A survey of emerging technologies, IEEE Communications Surveys & Tutorials 22 (2020) 1121–1167. doi:10.1109/COMST.2020.2973314.