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Bibliometric Analysis of Trust in Named Data Networking: Insights and Future Directions

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ABSTRACT

Trust plays a crucial role in the success and adoption of Named Data Networking (NDN), a data-centric communication paradigm. This paper presents a bibliometric analysis of research articles related to trust in NDN, aiming to provide insights into the current state of this research. Based on the conducted analysis, it was discovered that a total of 106 research papers pertaining to trust in NDN were published within the period of 2017 to 2023, as documented in the Scopus database. To better understand the present state of trust in NDN research and where the field is headed, four questions were formulated based on this topic . Several tools have been used in this study, including Microsoft Excel, OpenRefine, VOSviewer, Biblioshiny and Harzing's Publish or Perish. The observed trend indicates a notable increase in the quantity of articles published in the NDN journal during the periods spanning from 2017 to 2018, as well as from 2021 to 2022. The analysis revealed that China emerged as the nation with the highest number of published works, closely trailed by the United States. We expect many more regions to explore NDN in the future, and as a result, our collective understanding of the Internet's path will grow. This bibliometric analysis serves as a valuable resource for researchers, providing an overview of the current state of trust research in NDN and guiding future investigations in this evolving field.

1. Introduction

The Future Internet Architecture Program of the National Science Foundation of the United States provides its support to NDN, which is one of the five initiatives under the program's umbrella [1]. Content-Centric Networking (CCN), initially introduced by Van Jacobson in 2006, stands as a predecessor to NDN. Jacobson proposed a paradigm shift in network architectures, advocating for a transition from the prevailing host-centric model, represented by the Internet Protocol (IP), to a data-centric approach. In line with this vision, the NDN project is currently engaged in a comprehensive exploration of this alternative. The NDN paradigm introduces a modification to the conventional definition of network service. Specifically, it replaces the notion of "delivering the packet to a defined destination address" with the concept of "retrieving data identified by a provided name" [2].

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The NDN communication paradigm is a new approach that focuses heavily on data-centric communication and retrieval. This means that instead of traditional communication methods that revolve around sending and receiving messages, NDN prioritizes the exchange and retrieval of data. In the context of communication, the increasing importance of data necessitates the establishment of trust within the NDN network as a fundamental requirement for facilitating secure and dependable data interchange [3]. Trust in NDN extends beyond conventional network paradigms that primarily emphasize the security of communication channels. Instead, NDN seeks to establish trust in the content itself, the authors or data producers, and the overall network environment [4]. Through a comprehensive assessment of the trustworthiness of the NDN network, this endeavour seeks to create an environment of confidence among consumers regarding the accuracy, authenticity, and quality of the data they acquire.

In the involving landscape of NDN, trust management emerges as a critical area, yet it remains underexplored and fragmented in current research. The complexity of trust in NDN, characterized by its decentralized architecture and dynamic data flows, poses significant challenges in establishing reliable trust models. A bibliometric analysis of the existing literature reveals a gap in comprehensive understanding and systematic mapping of how trust is conceptualized, managed, and evolved within the NDN paradigm. There is a notable lack of studies synthesizing the diverse approaches to trust management, leading to a fragmented knowledge base. This gap is further widened by the limited focus on interdisciplinary approaches that integrate technical, social and ethical dimensions of trust in NDN. Moreover, the current literature lacks a detailed exploration of the most influential authors, articles and geographical contributions in this domain, which is crucial for understanding the development and dissemination of trust-related concepts in NDN. Addressing these gaps through a bibliometric analysis will not only provide a structured overview of the field but also identify key trends, influential works and potential future research directions, thereby contributing to a more cohesive and comprehensive understanding of trust in NDN [4-6].

The purpose of conducting this bibliometric analysis is to facilitate a thorough and comprehensive awareness of trust within the context of NDN, given its numerous and complex environments. By conducting this bibliometric analysis, researchers can gain a holistic view of the field and identify knowledge gaps or areas that require further investigation [7,8]. Furthermore, bibliometric analysis also enables the identification of trends, patterns, and emerging research themes in trust in NDN. It helps researchers understand the trajectory of research, the evolution of ideas, and the areas that have received significant attention. By conducting an in-depth examination of the current state of NDN research, we aim to identify key areas for improvement and propose a comprehensive roadmap for future investigations. This paper also offers valuable insights and recommendations that will not only benefit our fellow scholars but also contribute to the advancement of NDN as a whole.

This paper presents a thorough bibliometric analysis of NDN and investigates the literature pertaining to trust in NDN. To accomplish this objective, the following research questions must be addressed:

RQ1: What are the current states of publications with regard to trust in NDN?
RQ2: Who are the most productive authors and countries in this area?
RQ3: What are the most influential articles in the area of trust in NDN?
RQ4: What are the future research directions?

The subsequent sections of this document are structured as follows: Section 2 will delve into the methodology employed for the bibliometric analysis and the data utilized in the study. In Section 3,

the findings and analyses pertaining to all of the research questions are presented and discussed. In conclusion, Section 4 elucidates the research's findings.

2. Methodology

2.1 Bibliometric Analysis

Combining "metrics" with the words "bibliography," "information," "science," and "library" yields the names "scientometrics," "bibliometrics," "informetric," and "librametrics," respectively [10]. Since the primary domain and use include various parts of library and information science, these words are essentially interchangeable. All these concepts are closely connected to measuring knowledge, which relies on the development of new ideas via well-built information communication channels whose major goal is to enable the timely gathering and distribution of the most significant information for knowledge producers [11].

According to Pritchard [12], the term "Bibliometrics" is defined as the utilization of mathematical and statistical methodologies in the analysis of books and various modes of communication. This statement suggests that bibliometric analysis, a method employed to examine the characteristics of books (or, in the context of this study, to assess a body of literature), operates by utilizing bibliographic data as its foundation. For instance, the quantification of a compilation of literary works may be undertaken. An increasing group of scholars is gradually giving in to bibliometric analysis as a means to gain deeper insights into the comprehensive research environment [13]. The identification of emergent characteristics resulting from the research can be achieved through the classification of publications based on various criteria, such as the year of publication, authorship, affiliation, or country of origin, as applicable. Various metrics, such as the number of citations, the annual citation rate, the h-index, and the g-index, can be employed to evaluate the impact and performance of publications.

In addition, indicators like co-authorship, co-citation, appearances of keywords or concepts, and bibliographic coupling may be used to map and display the current state of the art of the publications. The accessibility of data that can be obtained from academic databases (such as Scopus, Web of Science, and Dimensions) and the availability of tools (such as VOSviewer, CitNetExplorer, and CiteSpace) has led to a rise in the number of studies using bibliometric analysis [14].

2.2 Data Analysis

The data presented in this article were taken from the Scopus database on September 8, 2023. Scopus was selected because it is constantly being updated and improved, making it one of the biggest searchable abstract and citation databases of academic articles alongside Web of Science and Google Scholar [8,9]. In this study, Scopus datasets from 2011 to 2022 are retrieved and have been cleaned using OpenRefine software. A total of 106 documents have been retrieved by using the following query: (TITLE-ABS-KEY (trust) AND TITLE-ABS-KEY (named AND data AND networking) OR TITLE-ABS-KEY (ndn)). All of the information extracted from Scopus has been saved as comma-separated values (.csv) and research information systems (.ris) files. Figure 1 is a flowchart depicting the search methodology.

In order to ensure the utmost quality and reliability, our document selection was restricted to peer-reviewed sources such as journal articles, conference proceedings and book chapters. The thorough peer-review process is crucial, as it ensures the reliability and expert validation of the content. This is vital for conducting a bibliometric analysis that aims to explore the research field objectively and comprehensively. We established specific exclusion criteria to refine our dataset

further, omitting types such as trade publications, short surveys, notes, reports and errata in the data searching phase. Our study encompasses a diverse linguistic spectrum, including documents in multiple languages, notably English and Chinese. The methodology of our search, including these selection and exclusion criteria, is comprehensively illustrated in Figure 1.

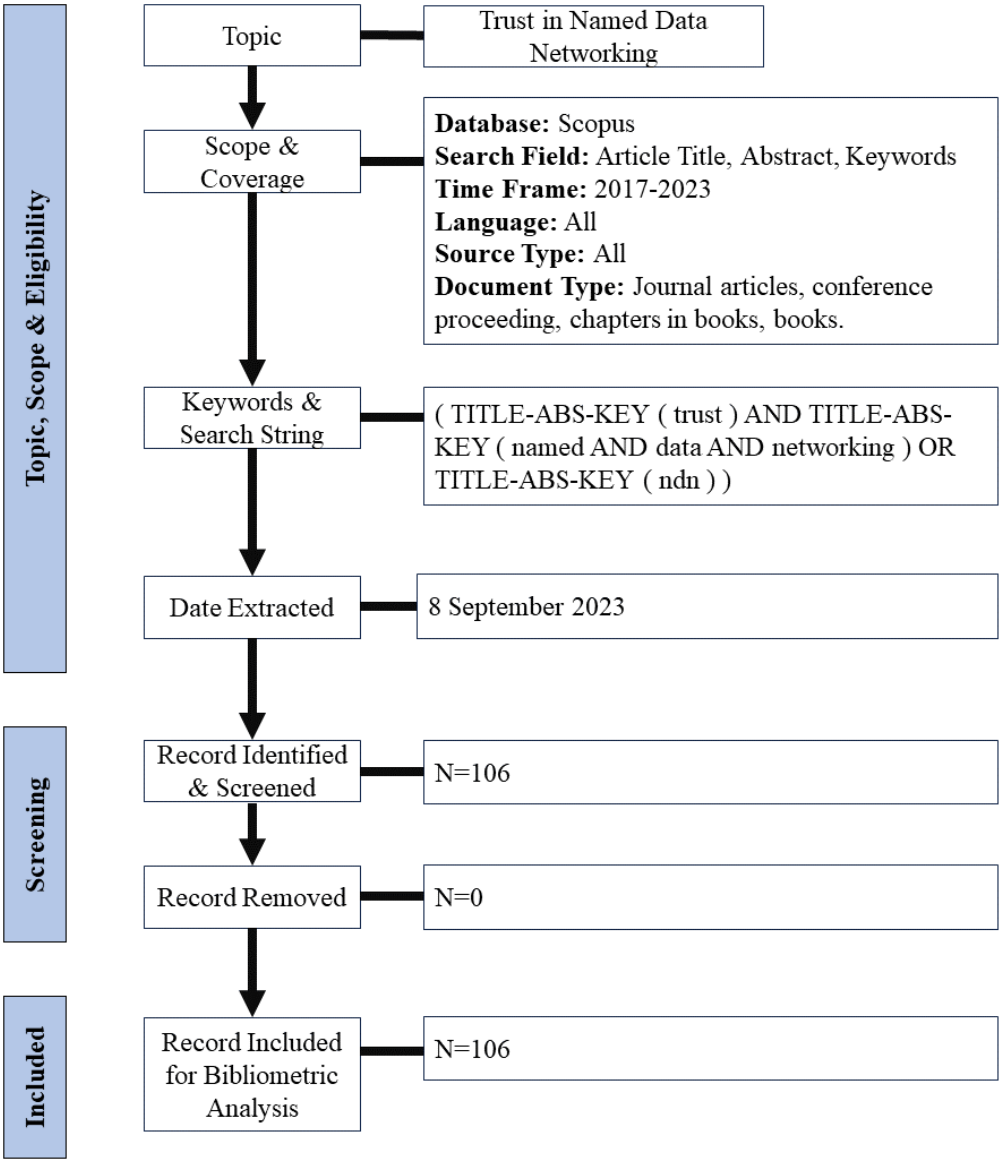


Fig. 1. Flow diagram of the search strategy [12,13]

The obtained data were utilized to create a visual representation illustrating the increase in publications and cumulative citations of scientific articles pertaining to trust in NDN from 2017 to 2023. This research utilized VOSviewer software (version 1.6.17), Microsoft Excel, OpenRefine, Biblioshiny and Harzing's Publish or Perish for the visualization of bibliometric networks due to its user-friendly interface and extensive range of visualization features. The subsequent section will present an analysis of the data collected and its alignment with the research questions previously formulated.

3. Results and Discussion

3.1 Current State of the Research

The search in the Scopus database turned up a total of 106 scientific articles from 2017 to 2023. Figure 2 shows the number of scientific articles published on trust in NDN and how many times they have been cited from 2017 to 2023. By looking at the documents based on the year they were published, we can see how the number of publications has grown over time. The highest productivity was in 2018, with a total of 24 documents, while the lowest was in 2021, with a total of seven publications. There was a general increase in the number of documents during the study period, with a slight drop from 2021 to 2023. Due to the short duration since publication, this is to be anticipated.

First, the acquired information would be analysed according to the nature and origin of the original document. The validity of a document determines the specific form of document it is, such as a journal article, a book chapter, a presentation at a conference, etc. On the other hand, source type indicates the nature of the document's origin, such as a journal, conference proceedings, book series, book, or trade publication. There is a chance that the format of the conference paper will vary from the original paper. For instance, the document type for conference papers is "conference paper". Depending on where it was first published, the same piece may be categorized as either a full-length journal article, a conference proceeding, or a book chapter.

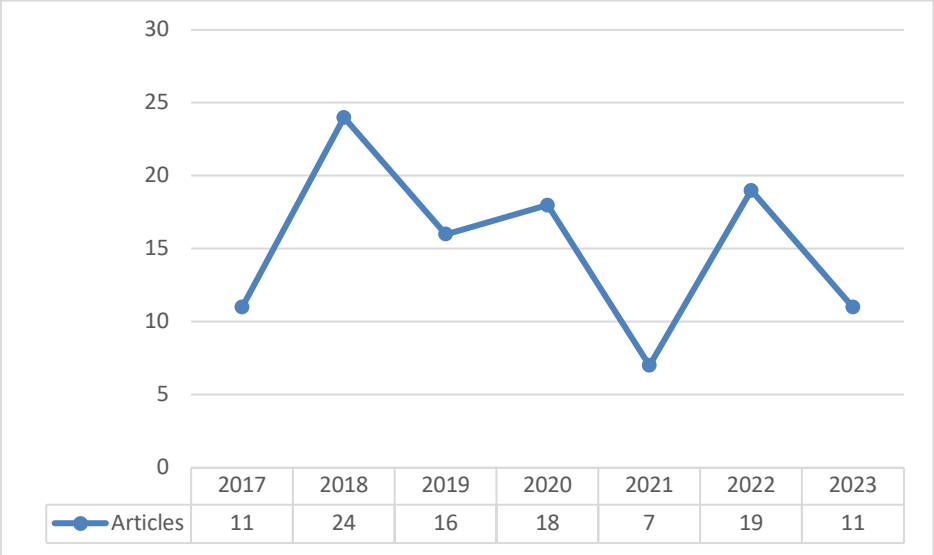


Fig. 2. Growth of publications between 2017-2023

The documents published on trust in NDN have been classified into six types of documents, as summarized in Figure 3. As shown in the figure, the overall publications are classified as conference papers (52 articles) and articles (43 articles). While other types of documents comprise less than 4 articles of the overall publications.

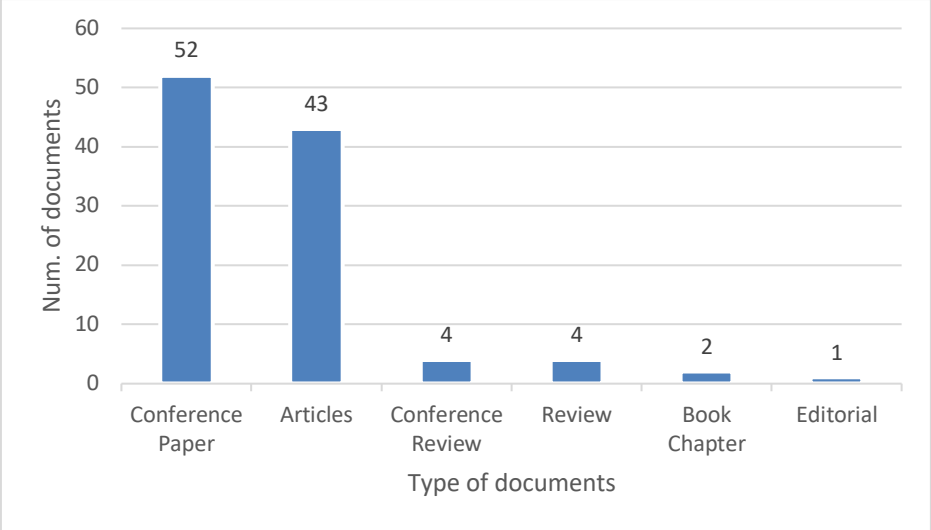


Fig. 3. Distribution of document types

Based on all the documents gathered from the Scopus database, trust in NDN covers almost all subject areas, indicating a great diversity related to the research topics. Subject areas within the selected documents tend to overlap (e.g., Finance and business). Rather than restricting a document to one field, the Scopus database tended to account for said overlap by allowing for multiple categorizations based on the content's multidisciplinary nature.

Figure 4 indicates which subject areas give focus to trust in NDN. Generally, the distribution reveals that literature in trust in NDN occurs in different fields such as “Computer Science, Engineering, Mathematics, Decision Sciences, Materials Science, Business, Management and Accounting”. As illustrated in Figure 4, the highest documents analysed are in Computer Science (45.6%) and followed by Engineering (23.3%). The least discussed subject areas in the area of trust in NDN are Economics, Econometrics and Finance, and Medicine (1.4%).

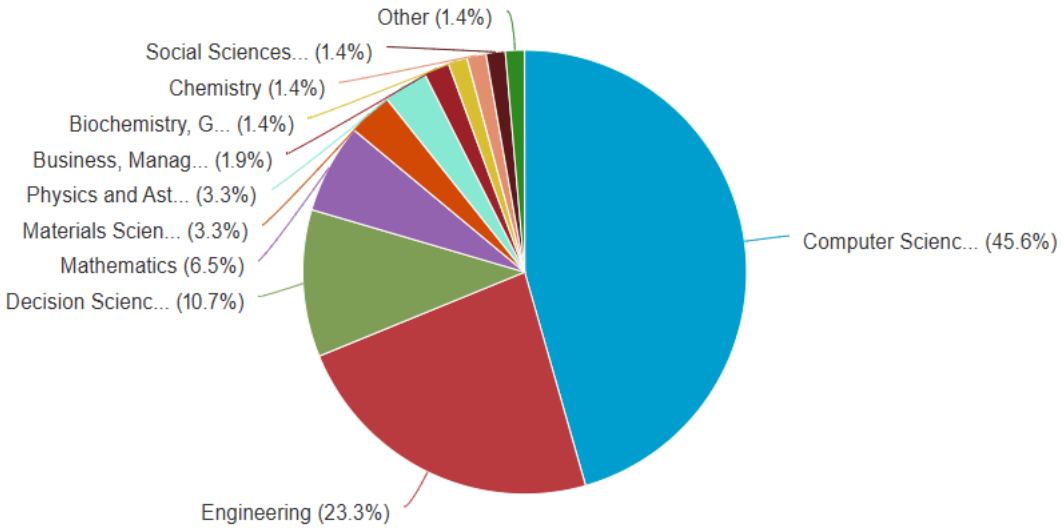


Fig. 4. Distribution of subject areas

In addressing the first research question (RQ1) which is the current state of the research on trust in NDN, a thorough examination of 106 scientific articles from the Scopus database, spanning 2017

to 2023, reveals significant insights. The fluctuating trend in publication numbers, peaking in 2018 and witnessing a slight decline from 2021 to 2023, underscores the dynamic nature of research in this field. The classification of these documents into various types, predominantly conference papers and journal articles, reflects the multifaceted approach to dissertating research findings. The diversity of documents in the NDN system covers a wide range of subject areas including Computer Science, Finance and Medicine, highlighting the interdisciplinary nature of trust in NDN. The data reveal a significant concentration of research in Computer Science and Engineering, indicating these fields' pivotal role in advancing trust in NDN. In summary, the current state of the research on trust in NDN focuses mainly on technical elements, primarily within the fields of Computer Science and Engineering, with an emerging trend towards interdisciplinary studies. Despite the recent dip in publication numbers, the field remains active, with ample scope for expansion into less explored areas, enriching the overall understanding and application of trust in NDN.

3.2 Most Active Authors and Influential Countries

This section aims to provide an analysis of the authors and countries that have had the most significant impact in the field of trust in NDN. To address the research question (RQ2) posited in the preceding section, an analysis is conducted on the authors with the highest productivity and countries that have made significant publications on the topic of trust in NDN from the years 2017 to 2023.

Based on the statistics, 310 authors wrote articles from 2017 to 2023 about trust in NDN. In this section, we present Table 1, which provides a comprehensive overview of the top 10 most productive authors during the research period. The authors' productivity is measured based on the number of publications they have contributed to within the specified timeframe. The inclusion of this table aims to shed light on the individuals who have made significant contributions to the field of study during the specified research period. In the realm of scholarly publications, the author who exhibited the utmost productivity with an exceptional number of publications was Wang, L., who contributed a remarkable total of eight publications. This remarkable achievement firmly established Wang, L., as a prominent figure in the field. Following closely behind, Zhang, L., secured the second position with an impressive tally of seven publications.

Table 1
Top 10 most productive authors

Element	h	g	m	Total Citation	Number of Publications
Wang L	6	8	0.857	161	8
Zhang L	4	7	0.571	119	7
Afanasyev A	4	6	0.571	59	6
Gawande A	3	4	0.429	60	4
Wang J	3	4	0.5	53	4
Ahmad F	3	3	0.6	84	3
Hussain R	3	3	0.5	73	3
Kerrache Ca	3	3	0.5	73	3
Moungla H	3	3	0.5	184	3
Nour B	3	3	0.5	184	3

This noteworthy accomplishment solidifies Zhang, L.'s standing as a significant contributor to scholarly discourse. Authors such as Wang L, Zhang L, and Afanasyev A, have the highest h-index and

g-index, indicating their work is highly cited and influential within the community. These authors likely have contributed significant research on trust mechanisms in NDN, which may include trust management, authentication, and security protocols. Table 2 displays the rankings of the top 10 most productive countries. Out of the top ten most productive countries, China produced 105 publications between 2017 and 2023, followed by the United States with 102. The findings of this analysis suggest that both China and the United States exhibit a higher pace of research in the field of NDN compared to other nations. These two countries appear to be at the forefront of NDN research, showcasing a notable level of activity and progress. Consequently, it becomes evident that there exists an opportunity for other countries to delve deeper into the study of NDN research, as the current landscape suggests room for further exploration and advancement in this domain. The data provided in this table offers valuable insights into the productivity levels of various nations. This most productive countries data can be used to identify potential collaborators and understand which regions are driving innovation in trust for NDN. Moreover, it may guide researchers towards influential authors and seminal works that could shape their own studies in NDN trust.

Table 2
Top 10 most productive countries

Country	Number of Publication
China	105
United States	102
India	41
Italy	17
Malaysia	13
Brazil	12
Greece	11
Tunisia	11
Japan	9
Saudi Arabia	7

Figure 5 illustrates the scholarly output of various countries over time regarding trust in NDN. It indicates a growing trend in research and publications, reflecting increasing interest and investment in the security aspects of NDN. The steep upward trajectory of China and the USA suggests that these countries are leading the charge in developing trust frameworks for NDN, which is a key component for its adoption and reliable operation. The progressive increase also highlights that trust in NDN is a dynamic and evolving research area, with broader international attention as evidenced by the participation of countries like Brazil, India, and others. This global effort denotes that trust within NDN is being recognized as a critical issue that demands collaboration and innovation across the international research community. Such an analysis would be useful for identifying leading contributors, understanding collaborative networks, and predicting future trends in trust research within the NDN paradigm.

In answering the RQ2 on the most productive authors and countries in the area of trust in NDN. The most productive authors in trust research within NDN from 2017 to 2023 were Wang, L. and Zhang, L., who published eight and seven documents respectively, establishing them as leading figures. China and the United States were the top contributing countries overall, with China publishing 105 works compared to 102 from the US, indicating their pace of research is higher than other nations. While China and the US currently lead the field, the data suggests room for more countries to participate. China especially has seen phenomenal growth in output that surpassed the US in 2023 by 3 publications, highlighting its growing research capabilities. Thus, Wang, L., Zhang, L.,

China and the US have made the most significant impacts as the highest producing authors and most active countries in this developing domain from 2017 to 2023.

China as the leading country in the area might be the effect of the country's push towards becoming a global leader in technology which extended to areas such as cybersecurity and network architecture, where trust mechanisms in NDN are critical. Additionally, digital drive innovation in China aligns with the need to develop secure and reliable data. Chinese researchers can lead large-scale research projects, leveraging their extensive publication record to attract international collaborators, share expertise, and consolidate fragmented knowledge bases.

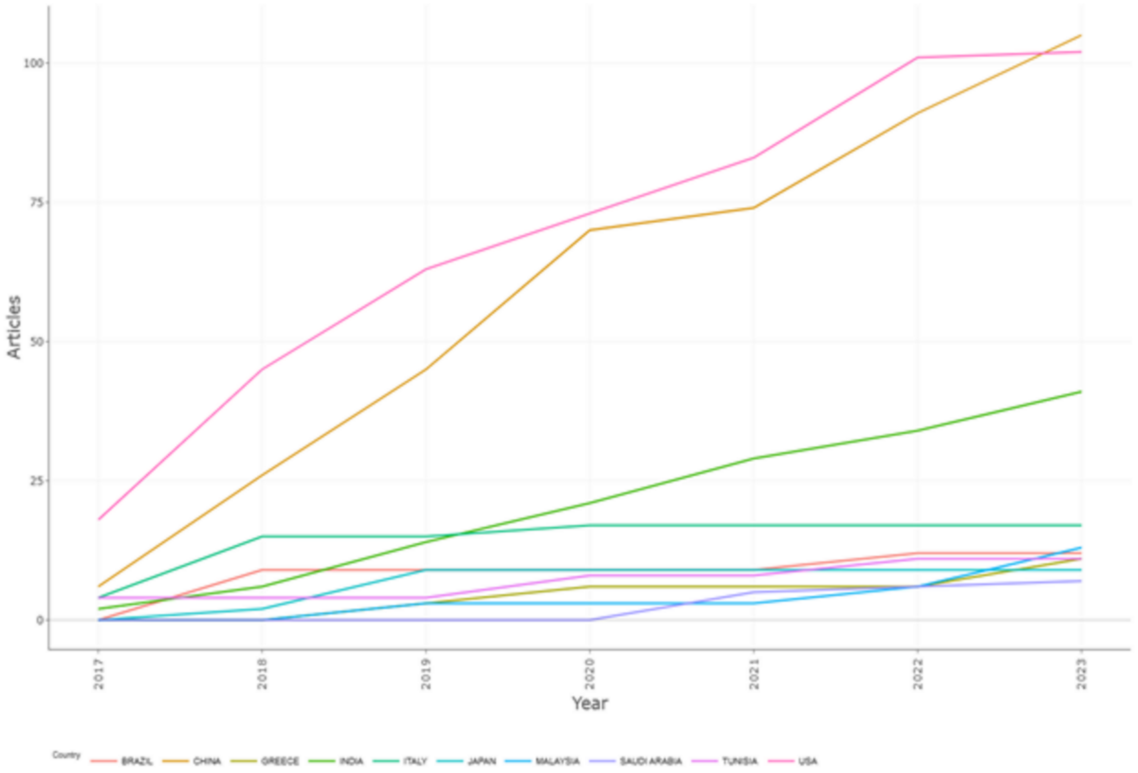


Fig. 5. Progression in time of countries' production

3.3 Most Influential Articles in the Area

In accordance with the inquiry posed by the third research question (RQ3), Table 3 describes the ten most frequently referenced papers pertaining to the domain of trust in NDN. The articles span from 2017 to 2020, indicating a focus on recent advancements and discussions within the field. The Table 3 indicates that the most influential article on trust in NDN is "Toward a blockchain cloud manufacturing system as a peer-to-peer distributed network platform", with 229 citations. This suggests that the integration of blockchain technology with NDN has garnered significant attention within the research community, highlighting the potential for enhanced security and trust management in distributed network platforms.

There is a strong emphasis on blockchain technology and its application in various domains, such as IoT (Internet-of-Things) and NDN, highlighting the importance of this technology in enhancing security and trust in distributed network platforms. The presence of articles related to IoT, such as "Policy-Based Secure and Trustworthy Sensing for Internet of Things in Smart Cities" and "A survey of Internet of Things communication using ICN: A use case perspective," shows that trust in NDN is

being extensively explored in the context of IoT, which is a growing area of importance. Other articles discuss secure routing protocols, reputation-based systems for vehicular networks, and trust management schemes, all within the context of secure and efficient data exchange. The articles exhibit varying citation patterns. Notably, the 10th most cited article, titled "FTM-IoMT: Fuzzy-Based Trust Management for Preventing Sybil Attacks in Internet of Medical Things," has garnered a noteworthy 46 citations. This substantial citation count indicates that the article continues to hold significance in the realm of network technologies and has garnered considerable attention from the academic community. Furthermore, the diversity of topics, including secure routing, blockchain for secure caching, and trust management, suggests a comprehensive exploration of trust within NDN, underlining its critical role in various applications and the innovation being undertaken to ensure secure and reliable data exchange in NDN networks.

Table 3
Top 10 most influential articles

Title	Year	Citations
Toward a blockchain cloud manufacturing system as a peer to peer distributed network platform [15]	2018	229
Policy-Based Secure and Trustworthy Sensing for Internet of Things in Smart Cities [16]	2017	132
A survey of Internet of Things communication using ICN: A use case perspective [17]	2019	98
A Secure Link State Routing Protocol for NDN [18]	2018	65
Survey on the Incorporation of NDN/CCN in IoT [19]	2019	57
Reputation-Based Blockchain for Secure NDN Caching in Vehicular Networks [20]	2018	54
Securing ICN-Based UAV Ad Hoc Networks with Blockchain [21]	2019	53
A trust management scheme to secure mobile information centric networks [22]	2020	49
Factors and characteristics that influence consumers' participation in social commerce [23]	2018	46
FTM-IoMT: Fuzzy-Based Trust Management for Preventing Sybil Attacks in Internet of Medical Things [24]	2020	46

3.4 Future Directions

This section aims to examine the thematic evolution and current trends of trust in NDN. This section is in accordance with the fourth research question (RQ4) regarding the future direction of NDN. This paper undertakes a thorough review of the current literature on trust research in NDN. By conducting an in-depth review of the existing literature, the paper aims to provide a comprehensive understanding of the principal themes and emergent concerns in this field. The goals of the RQ4 are to identify the future direction of trust research in NDN and highlight potential areas for further scholarly exploration. The thematic evolution encapsulated in Figure 6 offers a thorough view of academic pursuits, contributing significantly to crafting a scientific framework that will steer subsequent research initiatives.

The study of trust in NDN has witnessed a remarkable surge in research activity, demonstrating exponential growth in recent years. Scholars have diligently examined this topic from various perspectives, offering valuable insights into the complex dynamics of trust within the NDN paradigm. In light of our comprehensive investigation, it is proven that further inquiry is imperative to enhance our understanding of the intricate nature of NDN, specifically in relation to its numerous contextual circumstances.

It is expected that numerous domains will further investigate NDN in the forthcoming years. Moreover, the awareness of trusted networks within the future Internet is also projected to witness a notable enhancement. The rapid development of technological advancements necessitates a closer examination of trust distribution within the NDN network. In particular, the focus should be placed

on the complex interaction between trust, data integrity, and secure communication. The prioritization of NDN standards and routing is imperative, given the absence of an established standard for NDN at present.

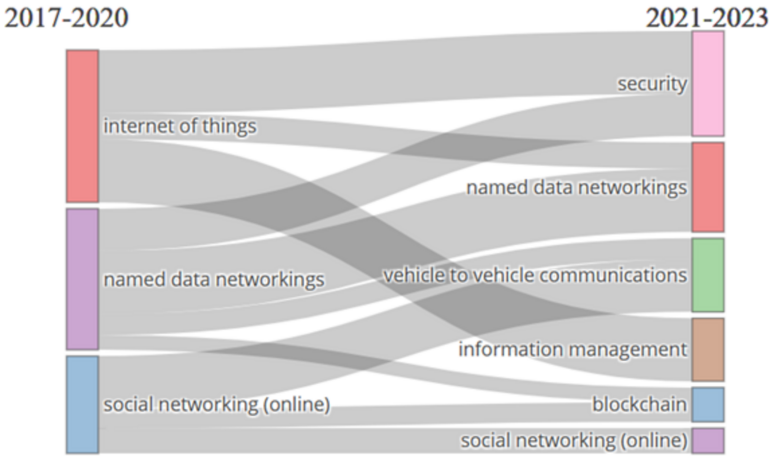


Fig. 6. Thematic evolution

Figure 7 compiles and displays the prominent terminologies related to trust in NDN literature from 2017 to 2023, with “Network Architecture” emerging as the term with the highest recurrence. Following closely are “trust” and “security”, following the most recent terminology in use pertaining to "vehicle-to-vehicle communications" and "named data networks". This highlights the scholarly community’s current focus on these areas, directing the momentum of NDN research towards enhancing trust mechanisms.

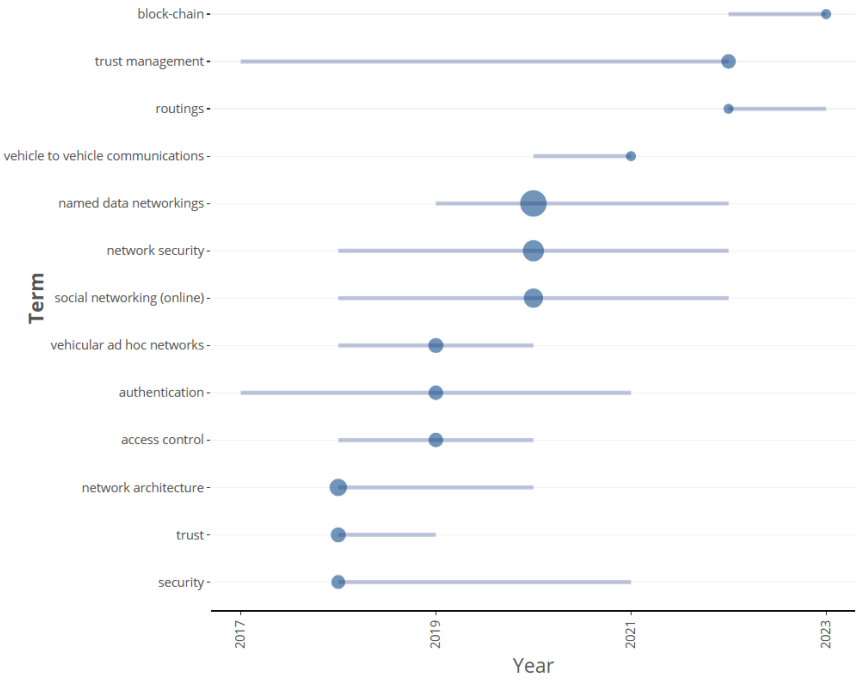


Fig. 7. Compilation of renowned terminologies

Given the ongoing acceleration in the publication of research on NDN, it becomes increasingly challenging to generalize and further elaborate on these findings. Moreover, it is important to acknowledge that potential gaps may exist between the current state of scholarly inquiry and the outcomes derived from our bibliometric investigation, given that certain recently published articles exhibit a diminished frequency of citations [25].

4. Conclusion

In summary, this bibliometric analysis has not only shown the progression of trust in NDN but has also identified key contributors, influential works, and geographical hotspots in the research domain. Our findings underscore the significant theoretical advancements made by prolific authors and leading countries, which have shaped the current understanding of trust in NDN. Importantly, this bibliometric analysis highlights a critical area for future exploration and presents fresh prospects for cooperation among scholars worldwide [26]. For example, China is the most productive country in this area. Collaborations with Chinese institutions could provide access to their research infrastructure as well as could lead to a more diverse interdisciplinary approach.

Practically, the insights gained from this study offer a roadmap for directing future efforts in NDN trust research. The identification of under-explored areas and emerging trends pave the way for innovative approaches to enhance data security and network reliability. This includes the development of Artificial Intelligence-driven trust assessment models that can dynamically adapt to changing network conditions of quantum-resistant cryptographic methods to fortify NDN against evolving security threats. Moreover, the study encourages the integration of blockchain technology for decentralized trust architectures emerges as a promising area, addressing the need for scalable and secure trust management in increasingly complex network environments.

In addressing these areas of trust in NDN, cross-disciplinary collaboration is essential. They bring together diverse expertise and perspectives, crucial for tackling the multifaceted challenges of trust in next-generation networks. Our analysis suggests that such collaborations can lead to more robust, efficient and user-centric trust solutions in NDN. Considering these findings, we recommend that future research not only continue to explore these identified areas but also expand the scope of bibliometric analyses.

Relying exclusively on the Scopus database for bibliometric analysis can introduce methodological limitations and potential biases, potentially distorting the findings. Despite its extensive coverage, Scopus may not encompass all literature, particularly in specialized or emerging fields. Integrating a variety of databases alongside Scopus can significantly enhance the breadth and depth of our understanding, offering a more comprehensive perspective of the field. This approach not only aids in uncovering novel insights but also opens avenues for further research. As the NDN paradigm evolves, it is imperative that our methodologies for analysing and enhancing trust within this domain evolve correspondingly, ensuring a robust and holistic understanding of the landscape.

Acknowledgement

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