ISSN: 0798-1015

REVISTA ESPACIOS

Vol. 41 (22) 2020 • Art. 28

Recibido/Received: 01/04/2020 • **Aprobado**/Approved: 05/06/2020 • **Publicado**/Published: 18/06/2020

Status quo of software-defined networking: a science mapping analysis based on CiteSpace

Status quo de las redes definidas por software: un análisis de mapeo científico basado en CiteSpace

CASTILLO, Edwin F. [1]
CAICEDO RENDON, Oscar M. [2]
RAMIREZ-GONZALEZ, Gustavo [3]

Abstract
The Software-Defined Networking (SDN) represents one of the most popular and attractive trends in academia and industry for defining the architecture of future networks. SDN simplifies network management and enables innovation through network programmability. This paper presents the Status Quo of SDN in a comprehensive and integrated approach. We discuss current trends in the publications of articles and explore promising research directions based on the SDN.
Key words: Software-Defined Networking, OpenFlow, CiteSpace, science mapping.

Resumen
La red definida por software (SDN) representa una de las tendencias más populares y atractivas en la academia y la industria para definir la arquitectura de las redes futuras. SDN simplifica la gestión de la red y permite la innovación a través de la capacidad de programación de la red. Este documento presenta el Status Quo de SDN en un enfoque integral e integrado. Discutimos las tendencias actuales en las publicaciones de artículos y exploramos direcciones prometedoras de investigación basadas en la SDN.
Palabras clave: Redes definidas por software, OpenFlow, CiteSpace, mapeo científico

1. Introduction

The exponential growth of IP traffic makes traditional networks complex to manage and implement new network policies and services (Jararweh, 2015). This complexity lies in the fact that the network devices have a tightly integrated control and data plane, and network administrators must separately configure every protocol (vendor-specific) on each device (Klein, 2013); (Cetinkaya, 2013). Thus, it makes the evolution of protocols difficult, leading to inefficient and fragile networks. Software-Defined Networking (SDN) is a paradigm that promotes a flexible architecture for fast and easy configuration of network devices. SDN has some distinguishing features that define how it is different from traditional networking architecture. These features include (Kreutz, Ramos, Verissimo, & Rothenberg, 2015); (Nunes, 2014): (*i*) clear separation of the control and forward function,

[1] Master student. Department of Telematics. Universidad del Cauca. efcastillo@unicauca.edu.co
[2] Full professor. Department of Telematics. Universidad del Cauca. omcaicedo@unicauca.edu.co
[3] Full professor. Department of Telematics. Universidad del Cauca. gramirez@unicauca.edu.co

(*ii*) centralization of the control function, (*iii*) implementation of the control function in software, (*iv*) open standards, and (*v*) Flow-based. These features make the SDN architecture more flexible, scalable, efficient and adaptable to the changing needs of the business (Vega, 2016); (Herrera, 2016).

SDN is currently attracting significant attention from academia and industry (Feamster, 2014). SDN covers a cross-disciplinary area with tremendous potentials, such as cloud computing, network virtualization, data centers, traffic engineering, energy efficiency, network security, and so on. Nonetheless, to the best of our knowledge, the current research has not focused on analyzing the status quo of SDN in a comprehensive and integrated approach. For example, in (Kreutz, Ramos, Verissimo, & Rothenberg, 2015), a comprehensive survey of the state-of-the-art of the programmable networks is carried out providing a historical perspective of SDN until 2014 and describing in detail its architecture. Nevertheless, such a survey does not provide a research status quo of SDN integrally. In this work, we present a longitudinal analysis of science mapping of the SDN research field; where we examine the research status quo of SDN in a comprehensive and integrated approach.

The remainder of this paper is organized as follows. In Section II, we describe the dataset and CiteSpace application. In Section III, we present the analysis of the relevant records, the publication contributions and academic influences of the most productive countries, universities, journals, and authors. In Section IV, we describe and discuss the research directions. In Section V, we provide conclusions and implications for future work.

2. Materials and methods

An observational, longitudinal and retrospective science mapping study was designed to expose the evolution and to identify the main research directions in SDN. Our study comes from investigations from 2011 to 2018.

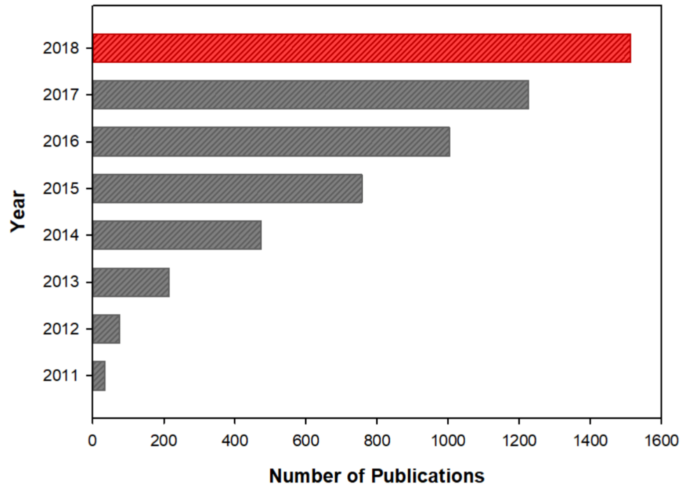
2.1. Data description

The fundamental part of a scientific map analysis is the data used in carrying it out. Therefore, sources of scientific information such as bibliographic databases are of vital importance. Nowadays, there is a great diversity of bibliographical databases available on Internet. These databases store the scientific documents, as well as citations between documents. Web Of Science (WOS), Scopus, and Google Scholar are the most widely known and used databases (Aghaei Chadegani, 2013). Our bibliometric study database was extracted from WOS (Rafols Ismael, 2010). This database was selected because it offers a set of metadata containing information about abstracts, authors, institutions, number of citations, references cited, and Journal Impact Factor (JCR), among others. It is noteworthy that these data are essential for conducting a bibliometric analysis.

We adopt the generalized definition of “Software-Defined Networking" as search criteria to generate the research database. The search resulted in 3876 studies, categorized by WOS in different research areas (*e.g.*, cloud computing, security, network management, and traffic engineering (see Figure 8).

Figure 1 depicts the cumulative number of published papers in each year. The difference in the trends between 2011 and the period 2012--2017 is significant because the number of all documents published increased from 34 articles in 2011 to 3751 in the period between 2012 and 2017. Furthermore, in this figure, it is observed a correlation between the number of publications and the publication year, resulting in a power curve (2012–-2017). From this curve, we could predict approximately a double increase in the number of future articles to be published in 2018 compared with the articles published in 2015. We calculate a forecast of roughly 1513 publications for the year 2018. This forecast is based on the assumption that the growth rate will maintain the same level found in the period 2012--2017.

Figure 1
Distribution of documents over the time for WOS



2.2. CiteSpace

CiteSpace is a Java application for visualizing and detecting trends and changes in scientific literature (Chaomei, 2006). CiteSpace identifies emerging topics or research directions in terms of highly cited articles, articles with citation bursts, subject categories, and keywords with a strong surge of a frequency of citation. The goal of burst detection is to determine whether the appearance of an entity increases sharply concerning its peers (Kleinberg, 2003). In particular, an article has a citation burst if the number of citations to the article is found to change dramatically over a short time, thus providing a key indicator of a research direction (Rincon-Patino J, 2018), (Chantre-Astaizac A, 2019), (Venkatraman, V. 2018).

CiteSpace allows configuring parameters as Text Processing, Links Selection, Selection Criteria, Pruning Method, Time Slicing, and so on, for getting more detail visualizations. *Time slicing* is one of the most relevant settings used to generate network visualization. For this study, we set the time slicing value in one (1). In this case, this scaling means that the entire time interval from 2011 to 2017 is divided into 1-year slices for processing. On the other hand, each point in the network visualization generated by CiteSpace (also called node) represents a document quoted and its thickness the number of citations received. Each line (link) assumes the co-citation relationship between two documents and their thickness and length the strength of their relationship. It is important to highlight that we use *Pathfinder network scaling* as the pruning method, commonly used to eliminate redundant name or connections.

3. Trends in the publications of articles

In this section, we discover and evaluate the contribution of the publications, the academic influences of the most productive countries, universities, journals, and authors in SDN context.

3.1. Authors

The productivity of the authors in a field is performed applying co-authorship analysis. Figure 2 depicts the co-authorship network formed by 421 nodes and 856 links. In this network, each node represents an author, and the relationship between the authors (link) represent co-authorship. Furthermore, the size of circles represents the number of publications, and the distance between two circles is inversely proportional to the collaboration between authors (*i.e.,* shorter distances suggest more collaboration).

Figure 2
Co-authorship network, with 421 nodes and 856 links

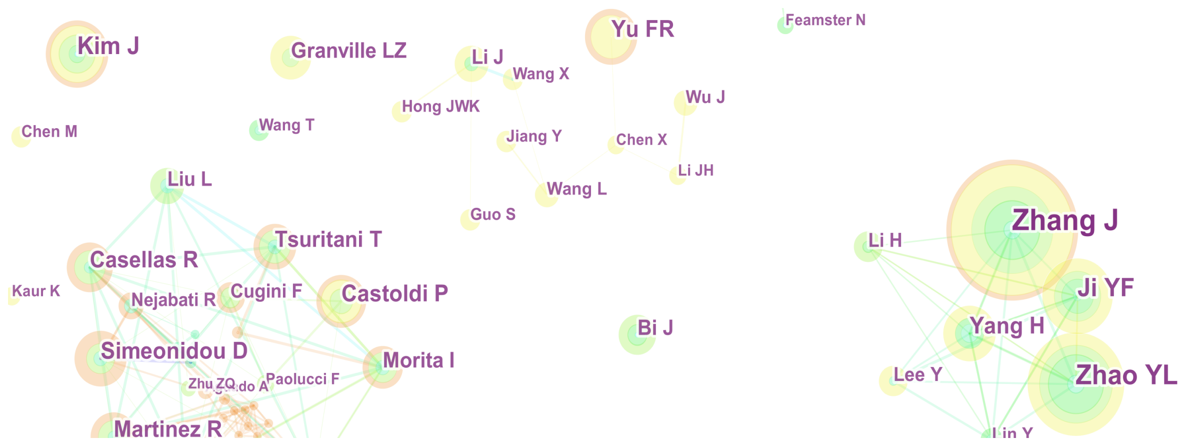


Figure 2 illustrates four points stand out from other points, revealing the co-authorship of the principal authors of the SDN research. In particular, Zhang Jie, Zhao YL, and Ji YF researchers and co-authors of the Beijing University of Posts and Telecommunications are the most productive authors in SDN (45, 33, and 24 articles, respectively), followed by Kim J researcher from Korea Electric Power Corporation (KEPCO) with 24 articles. The 10 most productive authors and some of their most important works are listed in Table 1.

Table 1
The top 10 most productive authors

Author	Total publications	Sample articles
Zhang Jie	45	(Yang, 2014); (Zhang J. a., 2013); (Zhang J. a., 2013)
Zhao YL	33	(Zhao Y. a., 2016); (Bhaumik, 2014); (Zhao Y. a., 2014)
Kim J	24	(Kim, 2015); (Kim J. a.-W., 2014); (Kim J. a.-W.-B.-Y., 2012)
Ji YF	24	(Yuefeng, 2013); (Ji, 2014); (Lai, 2003)
Casellas R	21	(Liu, 2013); (Casellas, 2015); (Casellas R. a., 2013)
Castoldi P	19	(Sgambelluri, 2013); (Giorgetti, 2012); (Sambo, 2011)
Simeonidou D	18	(Sideris, 2016); (Aguado, 2017); (Yan, 2017)
Yang H	18	(Yang, 2014); (Yang H. a., 2013); (Yang H. a., 2016)
Kellerer W	18	(Kellerer, 2015); (Sieber, 2016); (Basta, 2013)
Yu FR	18	(Liang, 2015); (Qiao Yan, 2015); (Liang, 2015)

In the same sense, the author co-citation analysis addresses the influence of author according to the citations, and it offers a glimpse of the structures inside a research domain (Small, 2009). The main idea is that the more frequently two authors are cited together, the closer academic relations between them (Zhang, 2016). Figure 3 illustrates the author co-citation network during 2011--2017, which containing 173 authors and 616 co-citation links. A link connecting two nodes in the network represents a co-citation relation. For example, the line connecting Casado, Feamster, and Koponen means that the articles are citing jointly the articles published by

Casado, Feamster, and Koponen. The size of each node reflects the number of citations of the author, and the co-citation frequency determines the thickness of a line. In other words, the academic relations between the authors whose publications are cited by the same articles can be explored through the author co-citation analysis (Song, 2016).

The most highly cited authors and their citation frequencies are apparent from the author co-citation network. The top 10 most cited authors and their most representative works are shown in Table 2. Nick McKeown, professor of Computer Science and Electrical Engineering at Stanford University and Faculty Director of Stanford's Open Networking Research Center (Where SDN and OpenFlow were developed under work (McKeown, 2008) and, whose motto is "*Software Defined Networking is the future. We are inventing it*" ranked first in the number of citations (1073), following by Kreutz D (345) and, Koponen D (266).

Figure 3

Author co-citation network, with 173 nodes and 616 links

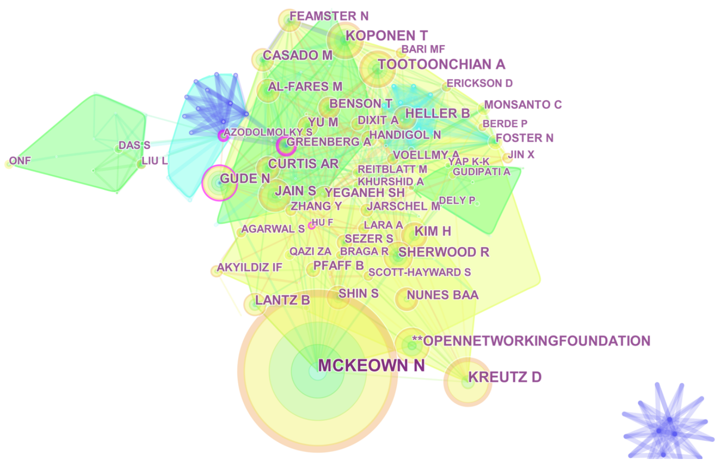


Table 2

The top 10 most cited authors

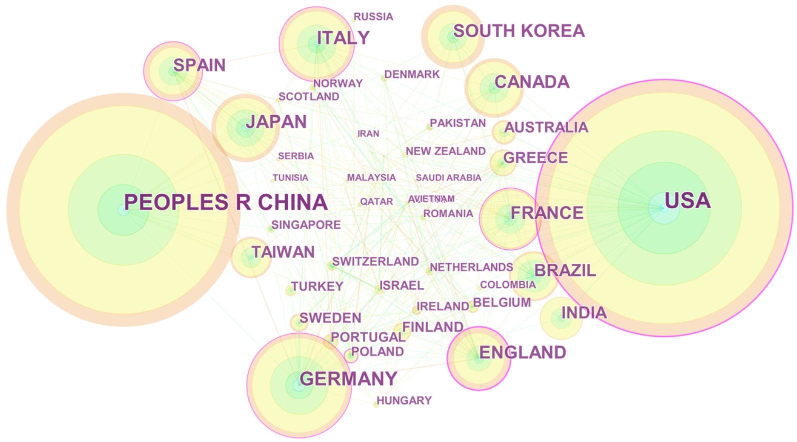
Author	Total citations	Most cited articles
MCKEOWN N	1073	(McKeown, 2008);(Gude, 2008)
KREUTZ D	345	(Kreutz, Ramos, Verissimo, & Rothenberg, 2015); (Kreutz, 2013)
KOPONEN T	266	(Gude, 2008); (Koponen, 2010)
ONF	261	
TOOTOONCHIAN A	256	(Tootoonchian, 2012); (Tootoonchian A. a., 2010)
GUDE N	243	(Koponen, 2010); (Gude, 2008)
JAIN S	238	(Jain, 2013); (Jain S. a., 2004)
SHERWOOD R	206	(Heller, 2012); (Sherwood, 2009)
KIM H	202	(Kim H. a., 2013); (Voellmy, 2012)
CASADO M	196	(Gude, 2008); (Koponen, 2010)

McKeown is an excellent reference in SDN. Furthermore, he has worked in co-authorship with some of the most cited authors in the SDN context. For example, the work presented in (Gude, 2008) McKeown did it in co-authorship with Gude, Koponen, and Casado and, in (Heller, 2012) the co-authorship was with Sherwood. It is important to mention that McKeown in 2007 co-founded Nicira (acquired by VMware) with Casado M and Scott Shenker. Furthermore, Nick is chairman of Barefoot Networks which he co-founded with Pat Bosshart and Martin

Izzard in 2013. In 2011, he co-founded the Open Networking Foundation (ONF) with Scott Shenker; and the Open Networking Lab (ON.Lab) with Guru Parulkar and Scott Shenker.

3.2. Countries

Figure 4
Country network, with 69 nodes and 323 links



The contribution by countries was estimated by focusing on the affiliation of at least one author of the published articles. Figure 4 shows that articles on SDN were a contribution from many countries spread over the entire globe. However, the significant contribution of research in SDN mainly came from twelve countries

Table 3
The top 12 most productive countries

Country	Total publications	Country	Total publications
USA	588	Republic of China	538
Germany	243	Italy	176
Japan	162	South Korea	151
England	146	France	143
Canada	141	Spain	136
Brazil	119	India	104

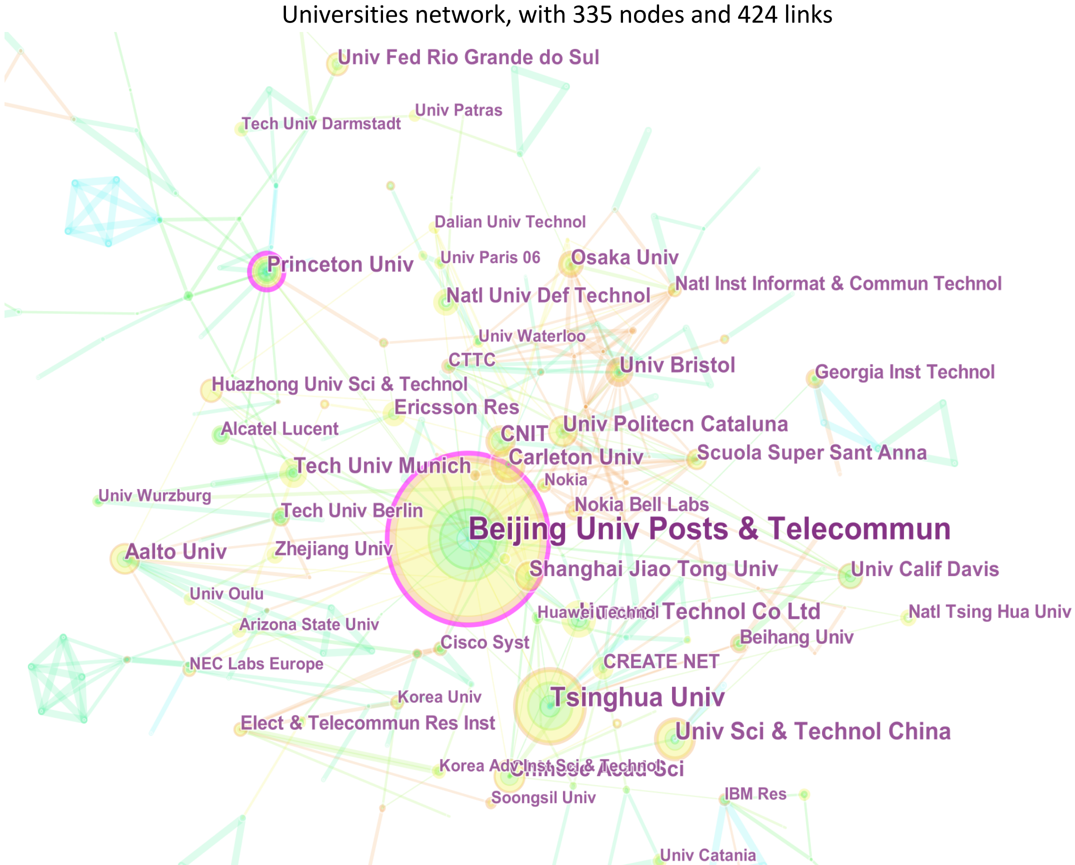
The frequency distribution of articles in Table 3 indicates that United States of America (USA) is not only the original participating country but also the most significant contributor publishing 588 articles in the field of SDN. Asian and European countries also are active in the research of SDN. The total of publications of China is 538 articles and ranks second. The other three prominent nodes come from European countries are Germany, Italy, and Japan with 243, 176, and 162 articles, respectively; ranking the third, fourth, and fifth regarding publication counts. There are still other countries participating in the research of SDN, such as South Korea, England, France, Canada, Spain, Brazil, India, Colombia, and so on.

Among the top 5 most productive countries for the year 2016, the citations per document of the USA is 23.58, Germany 19.7, Italy 17.5, Japan 14.98, and China 7.16. Furthermore, the h-index of the USA is 1965, Germany 1059, Italy 839, Japan 871, and China 655. The above data show that the articles from Germany, Italy, and Japan have more citations than Chinese articles; though China has greater amount articles published (see Table 3). This behavior could be caused by little collaboration scientific cooperation that China has with the other countries.

3.3. Universities network

The contribution of universities is estimated by focusing on the affiliation of at least one author of the published articles. Figure 5 identifies the distribution of universities most representative in the development of research in SDN. As mentioned earlier, USA and China possess a stronger research power in the field of SDN than other countries. The most important universities in the USA in the context of SDN are Princeton University and Arizona State University. In the same sense, the most important universities in China are Beijing University of Posts and Telecommunications, Tsinghua University, University of Science and Technology of China, Huawei Technologies Co. Ltd, so on.

Figure 5
Universities network, with 335 nodes and 424 links



It is noteworthy that Beijing University of Posts and Telecommunications cooperates widely with Tsinghua University, Princeton University, and other universities, in the development of research in SDN. The nodes that represent the universities of Beijing University of Posts and Telecommunications and Princeton University are framed with red rings, which indicate an accelerated growth in the number of publications of those universities. Although the node that the Princeton University is much smaller than the other nodes, the Princeton University is marked as a reference in the SDN context. The after mentioned result coincides with the most productive top 4 countries (Table 3) and the most productive top 10 authors (Table 1).

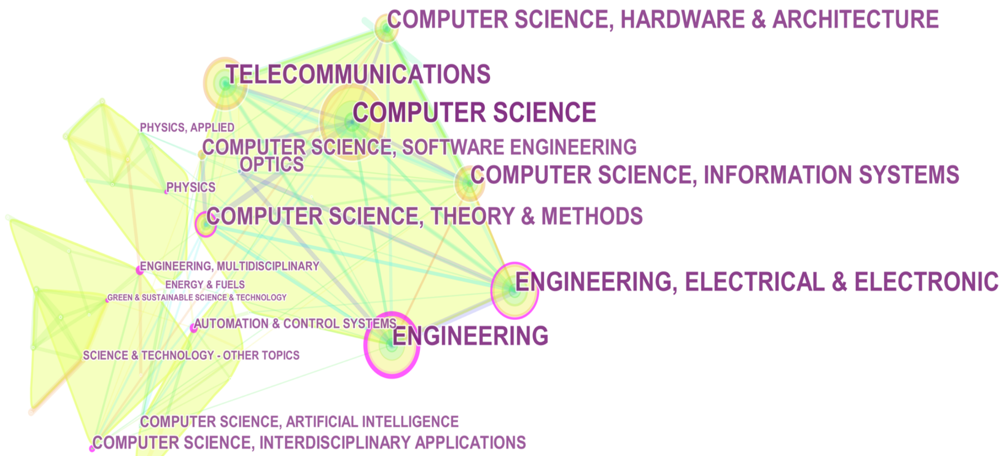
4. Research directions

In this section, we identify and discuss a non-exhaustive set of research directions of SDN. These research directions are the result of analysis of the categories and keywords most used by researchers to frame their research works in the SDN context.

4.1. Categories

CiteSpace can intuitively display the subject category distribution of articles. Figure 6 illustrates the distribution network of the subject category with 60 nodes and 170 links on SDN. Computer science is the leading subject category involved in the research of SDN with 1732 appearances, which correspond to 20% of all publications. According to the subject category statistics from the WoS, papers mainly distribute in its six branches, including Information Systems (901; 10.4%), Hardware & Architecture (690; 8%), Theory & Methods (549; 6.4%), Software Engineering (301; 3.5%), Interdisciplinary Applications (110; 1.%), and Artificial Intelligence (60; 0.6%). Engineering is the second largest subject category involved in the research of SDN, followed by Telecommunications ranking third. Both of them contributed 1288 and 1222 publications, respectively. Optics, Automation, and control systems rank fourth and fifth with 192 y 153 articles, respectively. Other subjects with publication frequencies varying from 18 to 60 also have made outstanding progress in this field, including Physics, Science & Technologic, Energy, and so on.

Figure 6
Network of co-occurring subject categories in WOS with 60 nodes and 170 links

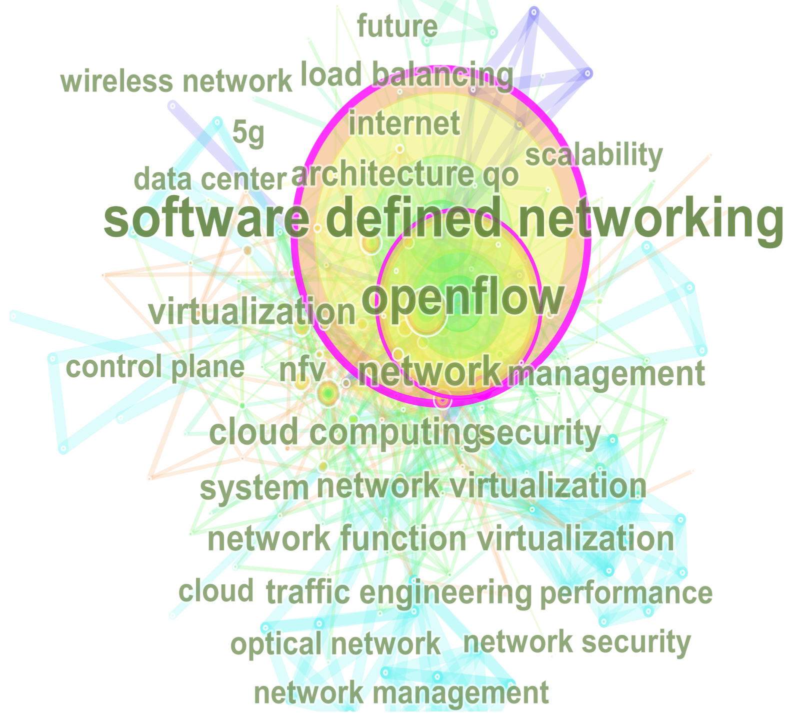


As the results indicate, there is strong interdisciplinary relations, a rapid diffusing and sharing of scholarly knowledge within the SDN research network. These results are because SDN is applied in different research fields and requires multidisciplinary capabilities from these areas to address multiples research challenges at the same time. SDN thus is the intersection in which many areas of research are fused.

4.2. Keywords

The analysis of keywords also help us identify research directions of SDN. Figure 7 shows a network of co-occurring keywords with 206 nodes and 769 links. In this network, the centrality of a node (i.e., which represents a keyword) is a graph-theoretical property that quantifies the importance of the node's position in a network. The Figure 7 shows that the centrality of the terms "Software Defined Networking" and "OpenFlow" is obviously outstanding. "Software Defined Networking" and "OpenFlow" are the keywords with the highest amount of occurrence at 828 and 486 times respectively. It is important to mention that, "OpenFlow" is the most deployed protocol to handle SDN-enabled devices (D. Kreutz, 2015), (A. Yassine, 2015), (Braun, 2014), and these two keywords should not be confused.

Figure 7
General network of co-occurring keywords, 2011-2017



To facilitate an efficient analysis and exclude irrelevant results, keywords that did not meet a co-occurrence frequency of two and the keywords “Software Defined Networking" and “OpenFlow" are omitted. These keywords were omitted because they are implicit terms in the field of SDN research. Figure 8 shows the network of co-occurring keywords after exclusion. This figure shows the keywords with the strongest bursts (label size) in their appearances during 2011 and 2017. The big label in the figure indicates fast-rising terms in titles and abstracts or most active topics. The most active topics include: ”Cloud Computing", “Network Virtualization", “Control Plane", and “Middlebox”. To statistically quantify the importance of each keyword within the co-word network. Table 4 lists the top 11 terms with co-occurrence frequency of over 30 occurrences.

Table 4
The top 11 author keywords

Keyword	Frequency	Keyword	Frequency
Network	127	Cloud Computing	77
Network Virtualization	67	Security	66
Network Management	58	Traffic Engineering	48
Load Balancing	47	Quality of Service (QoS)	46
Control Plane	42	Optical Network	41
Data Center	38		

Figure 8 and Table 4 expose clearly that the most frequently used terms are “Network" with 127 occurrences, “Cloud computing" with 77 occurrences, “Network Virtualization" with 67 occurrences, “Security" with 66 occurrences, and “Network Management" with 58 occurrences. Therefore, it can say that with the advent of SDN, most researchers have focused on the study of these terms.

Figure 8
Network of co-occurring keywords, with 206 nodes and 769 links

4.3. Future work

Cloud Computing redefines how computational resources and services are delivered and consumed. With Cloud Computing, distinct and distributed physical resources such as computing power and storage space can be acquired and used in an on-demand basis, empowering applications with scalability and elasticity at low cost (Rawat, 2017). In any cloud environment, the network is a critical resource that connects various distributed and virtualized components, such as servers, storage elements, appliances, and applications. Furthermore, the network enables delivery of cloud-based applications to the end users. Nonetheless, while every component in a cloud is getting virtualized, the physical network connecting these components is not. Without virtualization, the network is one traditional physical network, shared by all cloud end-users and cloud components.

Today, the networking industry has shown enormous interest in the SDN paradigm, given the expectations of programmable, virtualizable and easily partitional networks (Rubio-Loyola, 2011). There are currently significant research efforts in SDN context. However, some issues relating to SDN are still under active research in academia and industry. For example, more research is necessary on topics such as: guaranteed the performance of applications, flexible deployment of appliances (*e.g.*, firewalls, load balancing, and network monitoring), energy efficiency, network QoS management, security, and associated complexities to the policy enforcement and topology dependence (Azodolmolky, Philipp, & Yahyapour, 2013).

A Data Center is a set of servers, storage and network devices, power systems, cooling systems, etc. Data centers are intended for large-scale service applications such as online businesses, Smart Grid and scientific computation (Chen M. a., 2013); (Chen K. a., 2011). Data centers provide both physical and virtual infrastructures to a cloud computing system (*i.e.*, responsible for the QoS of connectivity and communication in the Cloud). Nowadays, data centers started adopting SDN concept to provide scalability and flexibility in your network resources. Giant cloud providers such as Google already adopted SDN concept in their data center to increase the scalability and manageability (Vahdat, 2015). Other proposals include Inter-connected data centers (Toosi, 2014), energy efficiency (Zhang Z. a., 2017), systems, security, storage; and networking (Jararweh & Al-Ayyoub, 2016), redundant network connection and ensure higher availability (Al-Fares, 2008); and network topology (Jararweh & Al-Ayyoub, 2016); (Bari, 2013); (Bilal, 2014); (Chen T. a., 2016). Activities in the cloud have specific networking requirements that facilitate and challenge the existing data center design.

In the following, we briefly present the key challenges related to management, testing, and validating the performance of data center components:

- How to locate the deployed services for achieving the best trade-off between performance and cost.
- How to manage effectively the services deployed in multiple data centers,
- How to map virtual resources to physical resources.
- How to manage the interaction between data centers and avoid resource allocation conflicts between them.

Network Virtualization allows flexible provisioning, deployment, and centralized management of virtual network functions (Azodolmolky, Philipp, & Yahyapour, 2013); (Ojo, 2016); (Costa-Requena, 2015). Integrated with SDN, the virtualization architecture further offers agile traffic steering and joint optimization of network functions and resources (Taheri, 2017); (Chen Y. L., 2015). The integration of SDN and Network virtualization benefit a wide range of applications, for example, service chaining (Fayazbakhsh, 2014); (Zhang Y. a., 2013); (Costa-Requena J. a., 2014), mobile networks (Li, 2012); (Jin, 2013), Middlebox (Sekar, 2011); (Gember, 2013); (Sekar V. a., 2012); (Sherry, 2012), among others. Nevertheless, despite the significant contributions of virtualization approaches aforementioned; there are several challenges and issues that need to be solved, including (Taheri, 2017):

- Design of southbound and northbound interfaces.
- Scalability, reliability, and high availability of the network,
- Placement optimization and resource allocation.
- Management and orchestration.
- Capability of sharing and slicing the network.
- Network performance requirements and evaluation methodologies.

In the past few years, research solutions have been presented to address some of the security issues introduced by SDN. For example, Unauthorized Access (Porras P. A., 2015); (Li H. a., 2014), Malicious Applications (Chandrasekaran, 2014); (Shin, 2014); (Porras P. a., 2012), Denial of Service (Fonseca, 2012); (Shin S. a., 2013), and Configuration Issues (Botelho, 2013); (Kazemian, 2013). The works on these solutions are developing encouraged by the increasing security focus of industry-sponsored standardization and research groups. Nonetheless, the current contributions are not yet mature enough for production deployment. Some challenges are identified such as unauthorized Controller Access/Controller Hijacking, Unauthorized/Unauthenticated Application, Credential Management, Controller-Switch Communication Flood, Data Leakage, and Data Modification (Scott-Hayward, 2013); (Scott-Hayward S. a., 2016). A strong theme is a projection of potential security issues and automated response for quick reaction to network threats.

Other high-frequency keywords abundantly cover the thematic contents of SDN research, as “Traffic Engineering – 48”, “Load balancing - 47"; and “Quality of Services - 46". Traffic Engineering (TE) selects the optimal paths that different flows should follow to optimize resource utilization and satisfy QoS requirements (Shu, 2016); (Smirnov, 2003). According to the Internet Engineering Task Force (IETF), TE aims to evaluate and optimize network performance, QoS and user experience of operational IP networks (Feamster, 2014); (Howarth, 2008). Below we list some works focused on TE: FlowSense (Yu, 2013), OpenSample (Carter, 2014); Payless (Boutaba, 2014); HONE (Sun, 2015); OpenSketch (Miao, 2013); Hedera (Al-Fares M. a.); Onix (Koponen, 2010); and BalanceFlow (Hu, 2012). Furthermore, recent proposals include optimization of rules placement (Nguyen, 2014), the use of

MAC as a universal label for efficient routing in data centers (Schwabe, 2014), flow management, fault tolerance, topology update, and traffic characterization (Akyildiz, 2014). The main goal of most applications is to manipulate the traffic with the aim of minimizing power consumption, maximizing aggregate network utilization, providing optimized load balancing, and other generic traffic optimization techniques. Although some applications are proposed at both data and control planes, there are still many open research problems to achieve a high reliability in SDN networks. Some of these research problems are traffic analysis, traffic monitoring, network invariant checking, programming error debugging method, traffic-adaptive primary-backup replication for the control plane, fast and cost-efficient failure recovery for data plane, dynamic load-balancing scheme for the data plane and control plane, and adaptive multi-flow table scheme (Akyildiz, 2014).

There is no doubt that TE is an important approach to handle SDN optimally. Traffic measurement is a key enabler to achieve the potential benefits of the TE on SDN; however, there are still challenges and several critical research issues. Where they stand out: flexible flow, efficient use of network resources, estimation modeling of traffic matrix, traffic monitoring and measurement integration in real-time, and traffic measurement for SDN Security.

In general, it is found that SDN research has main trajectories and trends as follows. First, according to the three highest-frequency keywords, it is evident that “Cloud Computing" and “Network Virtualization" have become a leading field of SDN in over the last years. Second, “Security", “Network Management"; and “Traffic Engineering", have become the currently most highlighted topics in the field of SDN research. Third, such words as "Cloud Computing" and “Virtualization", indicate that SDN may hold the center of research for future internet, which makes SDN a promising scenario for efficiently and intelligently implementing management techniques, network security, and particularly TE.

5. Conclusion

This paper takes advantage of CiteSpace to conduct a comprehensive and integrated analysis of SDN. From this analysis, we can observe that SDN is attracting increasing attention in academia and industry. Furthermore, considerable efforts have been made to ensure the successful operation of SDN. We explore the status quo and research directions of SDN development by mapping knowledge domains based on 3870 articles published between 2011 and 2018 collected from WOS database. The increasing number of bibliographic records over the last six years indicates that increasing attention is being directed toward SDN research as a platform for new generation networks.

SDN has successfully managed to pave the way towards a next generation networking, spawning an innovative research and development environment, promoting advances in several areas: cloud computing, data centers, evolution of scalability (network virtualization), traffic engineering, and promotion of security and dependability.

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