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Review

Survey Studies of Software-Defined Networking: A Systematic Review and Meta-analysis

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Abstract. Software-Defined Networking (SDN) represents a novel technological paradigm expected to dominate the next-generation networking. Since the emergence of SDN, there has been a significant increase in publications addressing a wide range of issues, leading to a proliferation of surveys and reviews. Consequently, due to the growing number of survey studies in the SDN domain, it has become imperative to establish a comprehensive taxonomy for these papers. This paper presents a systematic taxonomy for classifying, categorizing, and analyzing state-of-the-art survey research within the SDN field. Our systematic taxonomy process involves selecting reviews and surveys related to keywords such as 'SDN,' 'survey,' 'challenge,' 'taxonomy,' 'review,' and 'state-of-the-art.' We sourced these papers from reputable digital databases, including Web-of-Science (WoS), ScienceDirect, Scopus, and the Institute-of-Electrical-and-Electronics-Engineers' Xplore, all of which comprehensively cover recent literature. In total, we analyzed 442 survey and review studies published between 2012 and 2021, covering various journals and conferences with a focus on both general topics and specific subtopics of SDN. This paper represents the first epistemological study conducted on the literature of SDN. Our study aims to serve as a valuable resource for researchers, journal editors, and funding agencies, facilitating the identification of research gaps and making a significant contribution to future studies.

Keywords: Software defined networks, taxonomy, systematic review, classification.

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1. Introduction

The evolution of new communication technologies has led to a significant increase in data transmission. This shift necessitates networks to exhibit flexibility and dynamism to effectively respond to varying traffic conditions, network faults, security threats, and more. Software-Defined Networking (SDN) emerges as a promising and novel technology that offers programmability and flexibility to networks, thereby facilitating dynamic network management.

With the growing significance of SDN, the number of survey studies dedicated to this topic has gradually risen in recent years. These surveys delve into numerous specific aspects of SDN. However, novice researchers entering the field of SDN often encounter confusion due to the absence of a well-defined taxonomic structure for published survey studies, making it challenging to select an appropriate research area. This paper presents a systematic approach to classify various survey topics within the SDN literature. This systematic taxonomy provides a comprehensive perspective on the existing landscape while effectively identifying any gaps in the state of the art. Consequently, it offers a taxonomic framework for the issues related to SDN. Within this framework, all SDN survey papers published between 2012 and 2021 are meticulously classified and analyzed to reveal potential research areas. To our knowledge, this is the first comprehensive taxonomy that provides insights into the domain of SDN research studies. Table 1 lists the key Acronyms used in this article with their definitions.

The key contributions of this taxonomic review are highlighted as follows:

- We have developed a comprehensive thematic taxonomy that encompasses a total of 442 SDN surveys, including 298 journal articles, 135 conference proceedings, and 9 book chapters conducted between 2012 and 2021. This taxonomy offers a structured framework for categorizing and understanding the diverse landscape of SDN research.
- This survey provides insights into the publication trends of SDN survey papers by reporting the number of such papers published each year since 2012. This analysis offers an understanding of the growth and evolution of SDN research over time.
- We have compiled a list of academic journals in descending order based on the number of survey articles they have published, along with the quartile score of each journal. This information assists researchers in identifying reputable journals within the SDN domain.
- This survey includes a comprehensive analysis of the citations received by survey articles and their influence within the field of SDN. It lists the first 30 most cited articles based on citation rankings from Web of Science, Google Scholar, and Scopus. This citation analysis provides insights into the seminal works and influential research in SDN.
- The distribution of topics covered in survey studies has been categorized. This overview helps researchers and scholars identify prevalent research themes and areas of interest within SDN.
- The promising subtopics within the SDN domain were explored and examined, offering valuable guidance for future research endeavors. This analysis aids in identifying areas where further investigation and innovation are needed.

The remainder of the paper is organized as follows: Section 2 describes the epistemology of the SDN literature while Section 3 highlights the top topics of the SDN literature. Section 4 and Section 5, on the other hand, outline directions for future research and provide the conclusion, respectively.

Table 1. A list of acronyms used throughout the paper.

Acronyms	Definition
SDN	Software Defined Network
NFV	Network Function Virtualization
CPP	Controller Placement Problem
ICN	Information Centric Networking
IoT	Internet of Things
IP	Internet Protocol
P2P	Peer-to-Peer
QoS	Quality of Service
SDWSN	Software Defined Wireless Sensor Network
WSN	Wireless Sensor Network
GMPLS	Generalized Multi-Protocol Label Switching
ISP	Internet Service Provider
TLS	Transport Layer Security
TCP	Transmission Control Protocol
NETCONF	Network Configuration
BGP	Border Gateway Protocol
RESTful	Representational State Transfer
OSGi	Open Services Gateway Initiative
NBI	north-bound interfaces
SIP	Session Initiation Protocol
ONF	Open Network Foundation
NMS	Network Management System
QoE	Quality of Experience
AI	Artificial Intelligence
ML	Machine Learning
UCPP	Uncapacitated Controller Placement Problem
CCPP	Capacitated Controller Placement Problem
VANET	Vehicular Ad-Hoc Network
SDCC	Software-Defined Cloud Computing
LBR	Load Balancing Router
RLS	Realtime Least loaded Server

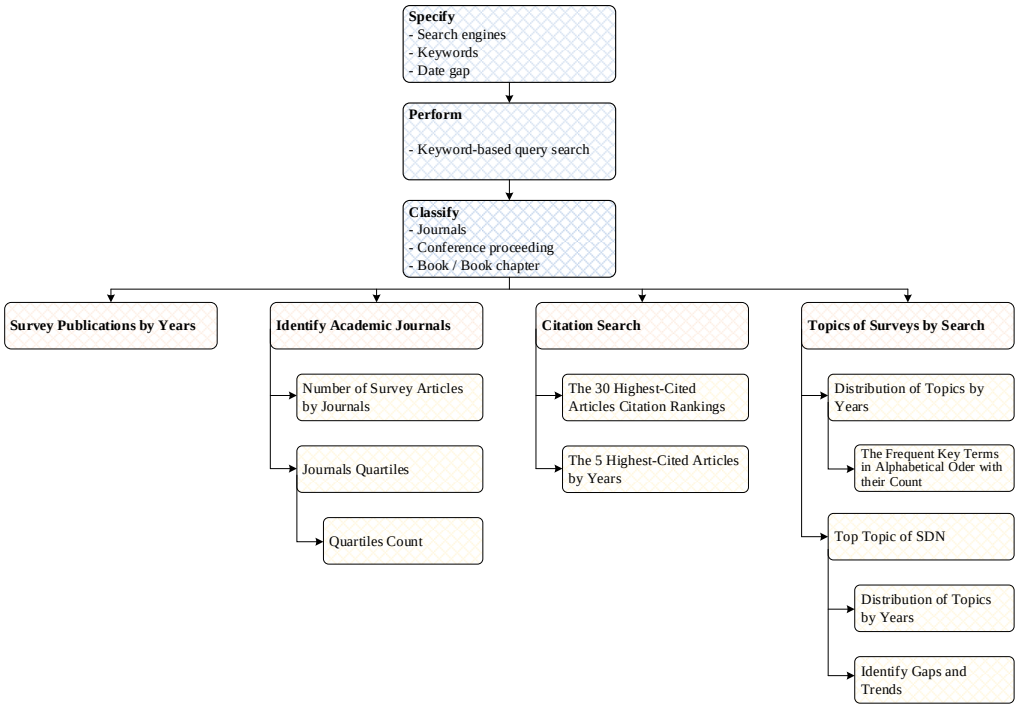


Fig. 1. The flow and tasks for the Taxonomic Review Process.

2. Epistemology of The SDN Literature

The overall process flow used in the taxonomic review of survey studies on SDN is illustrated in Fig 1. The process begins by specifying search engines, keywords, and a date range. We selected reputable literature search engines and databases, namely Web of Science (WoS), ScienceDirect, Scopus, and the Institute of Electrical and Electronics Engineers' Xplore, aiming to identify high-quality refereed research papers. This includes journal articles, conference papers, and books/book chapters. To initiate the keyword-based query search, we selected specific keywords such as 'SDN,' 'survey,' 'challenge,' 'taxonomy,' 'review,' and 'state-of-the-art.' Additionally, we applied a time filter (date range) to narrow down the search scope, focusing on papers published from 2012 to 2021.

Subsequently, we performed the keyword-based query search within the selected databases. After retrieving the search results, we examined the titles, abstracts, and metadata, including tags, to identify relevant papers. We then categorized these papers into different groups, such as journals, conference proceedings, books, or book chapters.

Within the scope of our proposed taxonomic classification, we list the survey articles, the number of survey publications by year, the academic journal names in which the surveys were published, and the number of survey articles according to the published journals and quartiles. In addition, with this classification, the number of survey studies, the top 30 most cited surveys or reviews in terms of citation rankings, and the top 5 most cited articles per year are ranked according to WoS, Google Scholar, and Scopus. All SDN survey studies are also classified according to their potential topics to provide better guidance to researchers. As a result of this classification, the distribution of the subjects by years, the frequently used key terms in alphabetical order, the number of these key terms, and the most important topics of the SDN research according to these key terms are given. Finally, we provide information about the most cited or most influential article(s) and journal(s) to assist researchers in identifying hot topics related to SDN.

2.1. Statistical findings

The query search resulted in 442 bibliographical entities which included 298 journal articles, 135 conference proceedings, and 9 book chapters as shown in the listing of the Table 2. Specifically, we exclude patents and non-scientific publications.

Table 2. Statistics of the survey studies in the SDN literature.

Publication Type	Count
Journal article	298
Conference proceeding	135
Book chapter	9
Total	**442**

2.2. The Survey Publications by Years

As shown in Table 2, the number of SDN survey studies is outrageously high. This is because SDN promises improved network resource utilization, simple

network management, flexible architectural design, and controllable and programmable networks with its centralized control. However, several SDN issues such as controller scalability and security, load balancing, NFV, cloud computing, 5G, etc. should be addressed with the growing number of users and equipment. Figure 1 depicts the number of SDN survey papers by year published since 2012. As can be seen from the distribution in Fig. 2, the number of survey papers has increased significantly especially in 2017, 2018, and 2019. We observed that 2019 had the highest number of survey articles about SDNs.

2.3. Names, Counts and Quartiles of the Academic Journals of the Published Surveys

Table 3 lists academic journals in descending based on the number of survey articles published. Table 3 clearly shows that IEEE Communications Surveys & Tutorials is the most preferred journal for the surveys. The second, third, and fourth preferred journals are IEEE Access, Journal of Network and Computer Applications, and Computer Networks, respectively. The quartile score of each journal is also indicated in the third column of Table 3. Among the 298 articles published in journal proceedings, 268 of them ranked in the Q1, Q2, Q3, or Q4 quartiles. Quartiles ranking of 268 journals is given in Table 4. Among the 268 journals, 155 of them are located in Q1, 55 of them in the Q2, 29 of them in the Q3, and 29 of them in the Q4 quartiles, as listed in Table 4. The 30 of the 298 articles which are listed in Table 3 do not appear in the Q1-Q4 quartiles.

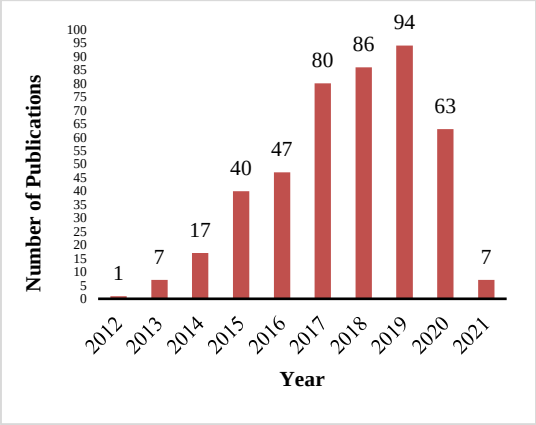


Fig. 2. The number of survey studies between 2012 and 2021.

Table 3. Listing of the survey studies in the SDN literature.

Journal's Title	Count	Quartile
IEEE Communications Surveys & Tutorials	40	Q1
IEEE Access	26	Q1
Journal of Network and Computer Applications	21	Q1
Computer Networks	15	Q1
Cornell University	9	-
IEEE Communications Magazine	7	Q1
IEEE Network	7	Q1
ACM Computing Surveys	5	Q1
Computer Communications	5	Q1
IEEE Internet of Things Journal	4	Q1
Wireless Personal Communications	4	Q3
Communications in Computer and Information Science	3	Q3
Electronics	3	Q2
Future Internet	3	Q2
Indian Journal of Science and Technology	3	Q4
International Journal of Scientific and Technology Research	3	Q3
Journal of Advanced Research in Dynamical and Control Systems	3	Q4
Journal of Network and Systems Management	3	Q2
Mobile Networks and Applications	3	Q2
Proceedings of the IEEE	3	Q1
Ruan Jian Xue Bao/Journal of Software	3	Q4
Security and Communication Networks	3	Q2
Wireless Communications and Mobile Computing	3	Q2
Advances in Intelligent Systems and Computing	2	Q3
Chinese Journal of Electronics	2	Q2
Computer Journal	2	Q2
Computer Science Review	2	Q1
Computers & Electrical Engineering	2	Q1
Concurrency and Computation Practice and Experience	2	Q2
Frontiers of Computer Science	2	Q1
IEEE Security and Privacy	2	Q2
IEEE Systems Journal	2	Q1
IEEE Wireless Communications	2	Q1
IIUM Engineering Journal	2	Q4
International Journal of Advanced Computer Science and Applications	2	Q4
International Journal of Advanced Science and Technology	2	Q4
International Journal of Applied Engineering Research	2	Q2
International Journal of Business Data Communications and Networking	2	Q4
International Journal of Computer Sciences and Engineering	2	-

International Journal of Network Management	2	Q2
International Journal of Recent Technology and Engineering	2	Q4
Lecture Notes on Data Engineering and Communications Technologies (Book Chapter)	2	-
Lecture Notes in Networks and Systems (Book Chapter)	2	-
Photonic Network Communications	2	Q2
Sustainable Cities and Society	2	Q1
Studies in Computational Intelligence (Book Chapter)	2	-
Telkomnika (Telecommunication Computing Electronics and Control)	2	Q3
Tongxin Xuebao/Journal on Communications	2	Q4
ZTE Communications	2	-
Advances in Intelligent Information Hiding and Multimedia Signal Processing (Book Chapter)	1	-
Advances in Wireless Communications and Networks	1	-
Applied Sciences	1	Q3
ARPN Journal of Engineering and Applied Sciences	1	Q2
China Communications	1	Q2
Cloud and fog computing in 5G mobile networks(Book Chapter)	1	-
Cluster Computing	1	Q2
Cogent Engineering	1	Q2
Computer Communication Review	1	Q1
Computer Software	1	Q4
Computer Standards & Interfaces	1	Q1
Computers & Security	1	Q1
Engineering technology & applied science research	1	-
Frontiers of Information Technology & Electronic Engineering	1	Q2
Future Generation Computer Systems	1	Q1
Gazi University Journal of Science	1	Q3
Handbook of Computer Networks and Cyber Security (Book Chapter)	1	-
IAIC Transactions on Sustainable Digital Innovation	1	-
IEEE Instrumentation & Measurement Magazine	1	Q2
IEEE Transactions on Network and Service Management	1	Q1
IEEE Transactions on Reliability	1	Q1
IEICE Transactions on Communications	1	Q3
IEICE Transactions on Information and System	1	Q3
IET Networks	1	Q2
IETE Technical Review	1	Q2
Information Sciences	1	Q1
International Journal of Advance Engineering and Research Development	1	-
International Journal of Applied Mathematics, Electronics and Computers	1	-
International Journal of Applied Science and Engineering	1	Q2
International Journal of Communication Systems	1	Q3
International Journal of Computer Networks and Wireless Communications	1	-
International Journal of Computing and Digital Systems	1	Q4
International Journal of Distributed Sensor Network	1	Q3
International Journal of Engineering and Computer Science	1	-
International Journal of Engineering and Technology	1	Q3
International Journal of Engineering Science	1	Q1
International Journal of Engineering Technology Science and Research	1	-
International Journal of Future Generation Communication and Networking	1	Q4
International Journal of Innovative Research in Computer and Communication Engineering	1	-
International Journal of Innovative Technology and Exploring Engineering	1	Q4
International Journal of Pharmacy and Technology	1	Q4
International Journal of Pure and Applied Mathematics	1	Q4
International Journal of Recent Trends in Engineering & Research	1	-
International Journal of Scientific Research in Computer Science, Engineering and Information Technology	1	-
International Journal of Web Services Research	1	Q3
International Journal of Wireless Information Networks	1	Q3

International Research Journal of Engineering and Technology	1	-
Internet of Things	1	Q2
IT-Information Technology	1	-
Jisuanji Yanjiu yu Fazhan/Computer Research and Development	1	Q3
Journal of Communications	1	Q4
Journal of Communications and Networks	1	Q2
Journal of Computational and Theoretical Nanoscience	1	Q4
Journal of Computational Science	1	Q1
Journal of Computers	1	-
Journal of Computer Networks and Communications	1	Q2
Journal of Cyber Security Technology	1	-
Journal of High-Speed Networks	1	Q3
Journal of Industrial Information Technology and Application	1	-
Journal of Intelligent and Fuzzy Systems	1	Q2
Journal of Internet Technology	1	Q3
Journal of Sensors	1	Q2
Journal of Supercomputing	1	Q2
Journal of Systems Architecture	1	Q2
KSII Transactions on Internet and Information Systems	1	Q3
Lecture Notes in Electrical Engineering	1	Q3
Peer-to-Peer Networking and Applications	1	Q2
Physical Communication	1	Q2
Procedia Computer Science	1	-
Programming and Computer Software	1	Q3
Security and Privacy	1	Q2
Sensors	1	Q2
Sustainability	1	Q2
Transaction Emerging Telecommunications Technology	1	Q2
Transactions on Emerging Telecommunications Technologies	1	Q2
Vehicular Communications	1	Q1

2.4. The most cited survey papers

We desire to analyze the citations of the survey articles and introduce their influence in the domain of SDN. The first 30 most cited articles according to Web of Science citation rankings are listed in Table 5. Similarly, Google Scholar and Scopus citation results are represented in Table 5. We noticed that there is a correlation in the number of citations in Web of Science, Google Scholar, and Scopus. However, some entries have different rankings when compared according to Google Scholar and Scopus.

Table 4. Quartile rankings of the 268 journals.

Quartiles	**Count**
Q1	155
Q2	55
Q3	29
Q4	29
Total	**268**

The 5 highest-cited articles by years from 2013 to 2020 extracted from the citation rankings of Web of Science are given in Table 6. Naturally that the recent survey papers have not yet received many citations. However, it is clear that the most influential survey paper is apparently [1], which has 1907, 2275, and 4254 citation counts ranked by Web of Science, Google Scholar, and Scopus, respectively.

When the most cited publications are analyzed, it is seen that the studies conducted in the first years were generally concerned with the general SDN information. These studies have allowed the in-depth analysis of SDN, revealed their shortcomings, and have shed light on future studies to eliminate the weaknesses of SDN. As the number of studies increased, these studies were seen to be carried out with different disciplines. Working with different disciplines has led to the categorization of the SDN topic into subcategories. From the first years of SDN to the present day, it has been observed that the number of citations of the studies on security, wireless SDN, Internet of Things (IoT), 5G, Controller Placement Problem (CPP), Load Balancing, Vehicular Ad-Hoc Network, Cloud Computing, Artificial Intelligence (AI) and NFV in these subcategories are quite high.

Table 5. The 30 highest-cited articles in terms of citation rankings of Web of Science.

Articles	**Year**	**Web of Science**	**Scopus**	**Google Scholar**
[1]	2015	1907	2275	4254
[2]	2014	940	1282	2161
[3]	2013	479	651	1081
[4]	2015	354	496	865
[5]	2013	318	378	673
[6]	2016	299	396	606
[7]	2014	285	394	661
[8]	2014	273	335	666
[9]	2015	210	275	442
[10]	2017	195	268	439
[11]	2015	191	205	296
[12]	2016	177	246	393
[13]	2014	170	218	372
[14]	2017	162	226	313
[15]	2015	161	219	340
[16]	2015	144	183	324

[17]	2016	144	177	259
[18]	2016	140	171	302
[19]	2017	138	178	237
[20]	2014	133	183	352
[21]	2014	120	165	230
[22]	2014	118	150	238
[23]	2017	116	143	215
[24]	2017	116	136	233
[25]	2015	105	131	177
[26]	2016	103	136	215
[27]	2017	102	148	211
[28]	2017	97	124	208
[29]	2016	95	119	183
[30]	2017	93	131	204

Table 6. The 5 highest-cited articles by year in terms of citation rankings of Web of Science from 2013 to 2020.

Years	Articles	Web of Science	Scopus	Google Scholar
	[3]	479	651	1081
	[5]	318	378	673
2013	[31]	65	257	461
	[32]	6	17	36
	[33]	2	46	81
	[2]	940	1282	2161
	[7]	285	394	661
2014	[8]	273	335	666
	[13]	170	218	372
	[20]	133	183	352
	[1]	1907	2275	4254
	[4]	354	496	865
2015	[9]	210	275	442
	[11]	191	205	296
	[15]	161	219	340
	[6]	299	396	606
	[12]	177	246	393
2016	[17]	144	177	259
	[18]	140	171	302
	[26]	103	136	215
	[10]	195	268	439
	[14]	162	226	313
2017	[19]	138	178	237
	[23]	116	143	215
	[24]	116	136	233
	[34]	79	100	176
	[35]	60	80	136
2018	[36]	56	82	130
	[37]	54	65	103
	[38]	45	61	91
	[39]	74	97	153
	[40]	72	92	172
2019	[41]	25	31	50
	[42]	21	30	42
	[43]	20	26	33
2020	[44]	38	62	95
	[45]	16	18	25
	[46]	8	10	17
	[47]	7	16	18
	[48]	6	8	15

2.5. Classifications of the Published Surveys

In the literature, some survey articles are general surveys covering the broader picture of SDN and some survey articles only deal with specific aspects of SDN. Because of this, all survey papers are classified. This kind of taxonomy of SDN surveys may help to subcategorize the challenges and the potential research topics in the SDN literature. On the other hand, this taxonomy may guide all interested researchers and highlight the subtopics for new researchers in the SDN field. As some topics are intertwined, we mentioned each subtopic separately for detailed comparison. The distribution of topics of survey studies by years are listed in Table 7, and the most frequent keywords or key terms or subtopics, and their counts that appear in the survey articles are illustrated in Fig. 3. The key terms were selected primarily by reading "Title/ Abstract/ Introduction/ Conclusion" fields of the related article. For example, challenges of SDN 5G networks [52]. The paper is mainly introduced the architecture and also orchestration and control aspects of SDN 5G networks. For this reason, the main topic for this paper was selected as '5G.' However, [10] surveyed the network slicing concepts with a focus on 5G technologies by supporting NFV. Therefore, 'Network Slicing,' '5G,' and 'NFV' topics were selected as key terms for this paper. Many different subcategories can be addressed but each survey paper is classified by maximum of four different subtopics.

From Fig. 3, the most frequent key terms by descending order are Security, General, IoT, NFV, Wireless Sensor Network (SDWSN), Vehicular Ad-Hoc Network, Artificial Intelligence, Load Balancing, CPP, Cloud Computing, and 5G. We demonstrated some key terms separately after this part because the key terms of the topic are very related to each other and the subject is very close to each other.

3. Top Topics of SDN Research

We found that some of the sub-SDN categories were more emphasized in SDN studies. These studies, which are closely related to the subject of SDN and connected to each other, are examined in more detail in separate subtitles.

3.1. General SDN

The concept of SDN is examined more generally in the first years and the studies had more general features. It is seen in Fig. 4, Especially as the studies on SDN developed, the general SDN concept is divided into subcategories, and as the studies on the subcategories increased, the studies on the general SDN decreased.

General SDN articles are studies in which the subject of SDN is covered in general, and studies in this area are divided into different subcategories. In these studies, the basic principles of SDN and more important issues and studies were discussed. Some surveys on the various issues, challenges, and solutions in the designing, implementation, performance, and verification of SDN is presented [1, 21, 23, 26, 32, 34, 146, 148-149, 158-159, 161-164, 166, 168-169, 174-176, 178-181, 184, 186, 188-189, 192-194]. Some articles [2-5, 14, 152-154, 156-157, 160, 165, 167, 170-173, 177, 182-132, 185, 190-191, 195] focused on the concept of general SDN and its components.

Table 7. Distribution of topics by years.

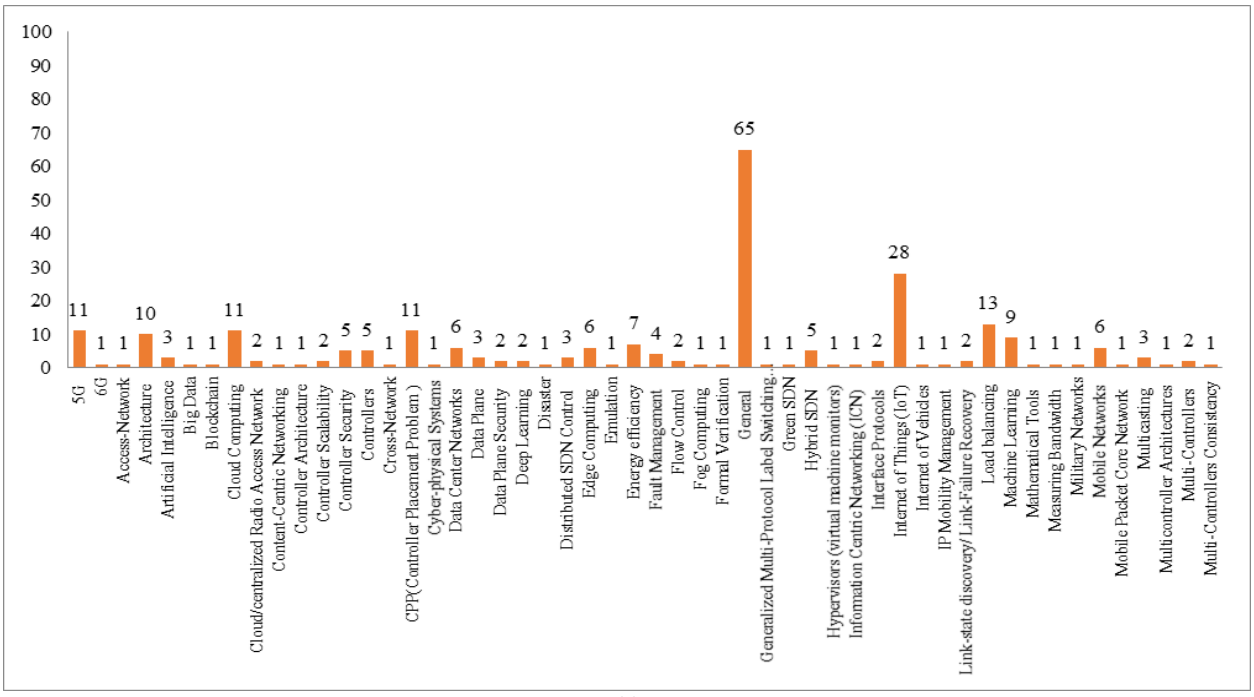
Topics	2021	2020	2019	2018	2017	2016	2015	2014	2013	2012
5G		[44], [49]	[50],[51]	[52]	[10], [53],[54] , [55], [56]		[57]			
6G			[51]							
Access-Network Architecture		[59], [60]	[61],[62]	[63],[64], [65]	[27], [66]		[58] [67]			
Artificial Intelligence			[68]	[69]		[70]				
Big Data		[71]								
Blockchain		[72]								
Cloud Computing		[73]	[74],[75], [76],[77], [78],[79], [80]	[81],[82]		[6]				
Cloud/centralized Radio Access Network		[83]			[84]					
Content-Centric Networking					[85]					
Controller Architecture					[86]					
Controller Scalability		[87]			[24]					
Control Plane Security			[88],[89]	[90],[91]	[92]					
Controllers	[93]		[94]	[95]	[96]		[97]			
Cross-Network CPP		[99]	[100],[42] , [101],[102], [103]	[98] [104], [105]	[106], [107], [108]					
Cyber-physical Systems				[109]						
Data Center Networks		[46]	[79], [110]	[111]	[112]		[113]			
Data Plane	[114]		[115]	[116]						
Data Plane Security				[117]	[118]					
Deep Learning		[119]	[120]							
Disaster						[121]				
Distributed SDN Control		[122]		[34]	[123]					
Edge Computing		[47], [124]	[125], [126], [125]		[19]					
Emulation									[127]	
Energy efficiency		[128]	[129], [130]	[131], [132]	[27], [133]					
Fault Management		[134]		[135]	[136]		[137]			
Flow Control			[138]	[139]						
Fog Computing				[140]						

Formal Verification		[141]							
General		[142]	[143], [144], [145], [146], [147], [148]	[149], [150], [151], [152], [153], [154], [155], [156], [157]	[158], [159], [160], [161], [162], [163], [164], [165], [166], [167], [168], [169]	[170], [171], [172], [173], [174], [175], [176], [177], [178], [179], [180], [181]	[4],[1], [182], [183],[16],[184], [185],[25],[186], [187], [188], [189], [190]	[7],[2], [8], [13], [191], [22], [20], [192]	[32], [3], [193]	[194]
Generalized Multi-Protocol Label Switching (GMPLS)						[195]				
Green SDN				[196]						
Hybrid SDN			[197]	[36], [198]	[199]			[21]		
Hypervisor (virtual machine monitors)						[18]				
Information Centric Networking (ICN)				[200]						
Interface Protocols		[201]	[202]							
Internet of Things (IoT)		[71], [203], [45], [204], [47], [205], [206], [207], [208]	[39], [126], [209], [210], [78], [211], [212], [213], [79], [214]	[140], [215], [216], [217], [218]	[219], [28]	[220], [26]				
Internet of Vehicles			[221]							
IP Mobility Management					[222]					
Link-state discovery/ Link-Failure Recovery		[223]	[138]							
Load balancing	[224]	[128], [225], [73], [226], [227]	[138], [228], [110]	[229], [230]	[231], [232]					
Machine Learning		[233]	[120], [40], [234], [235], [236], [68]	[237], [238]						
Mathematical Tools						[239]				
Measuring Bandwidth					[240]					
Military Network				[241]						
Mobile Networks				[242], [243], [244]	[245]	[246]	[247]			
Mobile Packet Core Network					[23]					

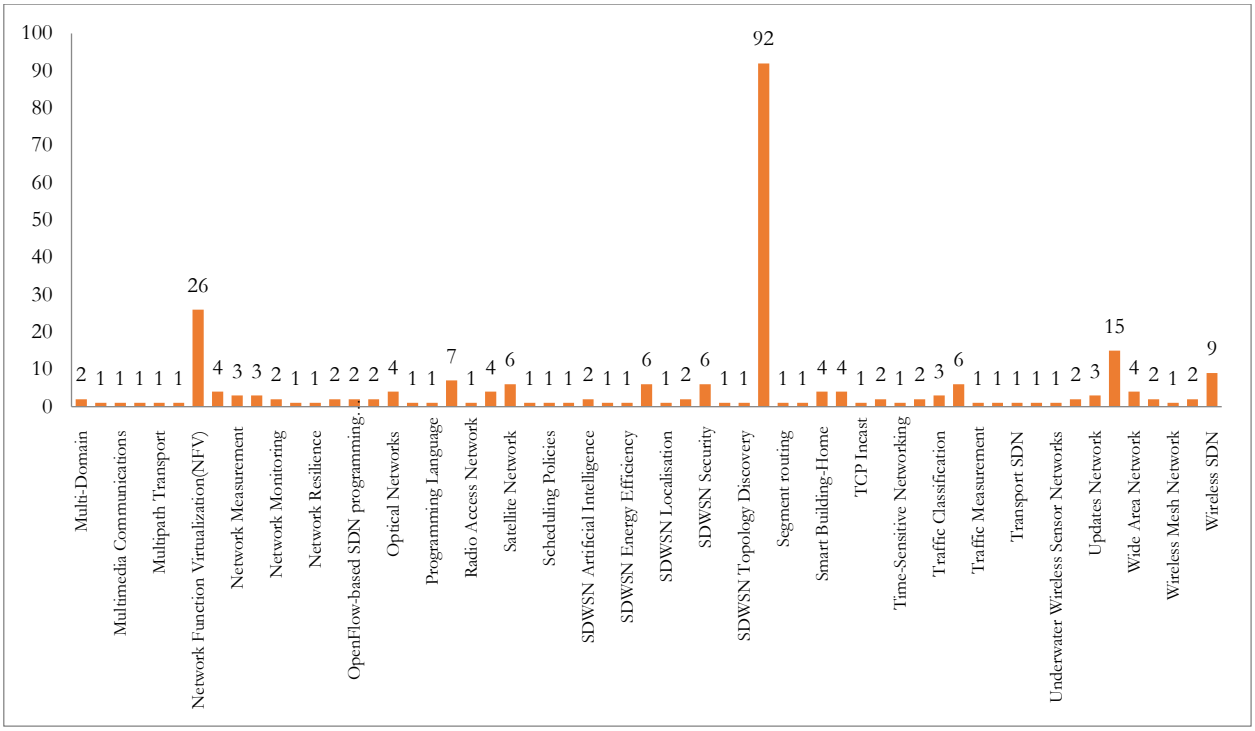
Multicasting			[248], [249]			[250]		
Multicontro-ller Architec-tures					[251]			
Multi-Controllers			[38],[37]					
Multi-Controllers Consistency			[252]					
Multi-domain				[253], [254]				
Multihop Wireless Networks				[255]				
Multimedia Communications		[256]						
Multi-Layer Network Arch.		[257]						
Multipath Transport				[258]				
Named Data Networking					[259]			
Network Function Virtualiza-tion (NFV)	[44], [208], [260]	[39], [261], [262], [41], [126]	[263], [264]	[265], [10],[23],[53], [55], [56]	[266], [26], [267], [268]	[11],[9], [269], [270] , [271]	[20]	
Network Virtualiza-tion				[272]	[273], [18]			[5]
Network Measurement		[274], [275]	[276]					
Network Management	[277]					[278]	[279]	
Network Monitoring	[280]		[281]					
Network Operators						[269]		
Network resilience						[282]		
Network Slicing	[44]			[10]				
OpenFlow-based SDN programming languages					[283], [284]			
OpenFlow rules placement problem	[285]				[286]			
Optical Networks					[17], [287]	[270]	[288]	
Peer-to-Peer (P2P) Streaming				[289]				
Programming Language					[290]			
Quality of Service (QoS)	[291], [292], [293]	[294], [295]	[296]	[30]				
Radio Acceess Network						[297]		
Resource Allocation-Managamenet	[298]			[299]		[113]	[300]	
Satellite Network			[301]	[302], [303]	[267], [268]		[304]	
Scalability						[305]		
Scheduling Policies				[306]				
SDN Platforms			[307]					
SDWSN Artificial Intelligence		[308]	[309]					
SDWSN Data-Aggregation		[310]						

SDWSN Energy Efficiency					[311]			
SDWSN General				[312], [313], [314]	[14], [315], [316]			
SDWSN Localisation			[317]					
SDWSN Management				[309], [35]				
SDWSN Security			[308], [318], [319]	[320]	[321], [322]			
SDWSN Smart-Grid Communication			[43]					
SDWSN Topology Discovery				[323]				
Security	[324], [325]	[72], [326], [327], [328], [329], [330], [331], [59], [203], [332], [48], [333], [334], [204], [335], [336], [337], [338], [207], [339], [340], [341]	[342], [343], [74], [344], [345], [346], [39], [347], [348], [349], [350], [351], [352], [235], [211], [213], [236], [353], [354], [355], [356], [357]	[358], [237], [359], [238], [360], [63], [361], [362], [363], [364], [365], [366], [367], [368], [369], [218], [370]	[219], [371], [372], [27], [373], [374], [375], [376], [377], [378]	[6],[12], [266], [379], [380], [381], [382], [246], [383], [384], [385], [386]	[15], [387], [388], [389], [390]	[391]	[31]
Segment routing			[392]					
Service Function Chaining		[393]						
Smart Building-Home		[336]	[261], [394]	[395]				
Smart-Grid Communication			[396]	[397]			[389]	[398]	
TCP Incast				[399]				
Testbed-Environment					[400]	[401]		
Time-Sensitive Networking			[402]					
Tools				[403]		[404]		
Traffic Classification		[119]	[120]	[405]				
Traffic Engineering	[406]		[407]		[408], [265], [409]	[410]		
Traffic measurement							[411]	
Topology Discovery					[412]			
Transport SDN					[413]			
Underwater Acoustic Sensor Networks			[414]					

Underwater Wireless Sensor Networks				[415]				
Unmanned Aerial Vehicles		[45]	[354]					
Updates Network			[416]		[417]		[418]	
Vehicular ad-hoc Network	[324]	[331], [419], [420], [421], [422], [337]	[423], [424], [425], [426]	[427],	[428], [429]		[430]	
Wide Area Network		[431]	[432]	[65]	[433]			
Wireless local area networks		[434]	[435]					
Wireless Mesh Network					[436]			
Wireless Network Virtualization					[84], [437]			
Wireless SDN				[367]		[220], [29], [438]	[439], [11], [440]	[441] [33]



(a)



(b)

Fig. 3. The frequent key terms in alphabetical order with their counts; (a) First 52, (b) Last 59.

The first of the survey studies on SDN was made in 2012 by [195] to introduce the framework of SDN in general. With the increase of studies on SDN in the following years, the number of general SDN surveys has also increased. Especially in the study by [1], SDN was handled comprehensively.

In addition to the increase of the General SDN surveys in 2015 - 2018, as the importance of SDN come out, new sub-categories have created to find solutions to different topics in this field. Due to more specific studies being conducted in different fields, survey studies on the general SDN decreased in 2019.

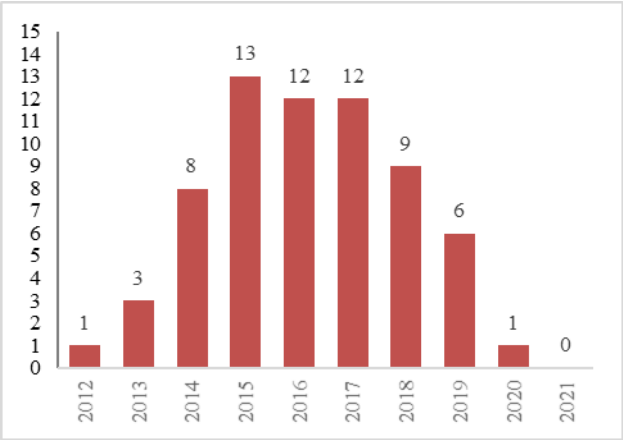


Fig. 4. Distribution of general survey studies on SDN by years.

3.2. Security

Changing the architectural design of the networks caused different requirements, especially in terms of network security. However, the fact that the SDN controller has programmable and has a global view of the network opens new ways for network security. Especially in our world where cyberattacks are increasing rapidly, it is necessary to dynamically configure and implement security policies to deal with cyberattacks.

Although the consequences of exploiting vulnerabilities in the context of SDN are of many different types, the proposed protection measures are mainly related to the network's access control (authentication, authorization, traceability) and flexibility protection (availability and integrity) and critical component areas.

While studies on SDN are increasing, security gaps in this area have also become more apparent. As seen in Fig. 5, studies in the field of security have increased over the years. Some of the studies in this area [2, 75, 93, 206, 326-329, 332-333, 335, 337, 347, 349, 356-357 361-363, 366-372, 376-377, 386] within the scope of centralized control feature, while forming the surveys of DDoS attacks and efforts to prevent general attacks, in some studies it has consisted of comprehensive security studies on SDN [9, 12, 28, 48, 59, 63, 202-203, 210, 212, 217, 234-235, 245, 324-325, 330-331, 334, 336, 338-341, 344, 348, 350-355, 364-365, 369, 374-375, 378, 380-381, 383-384, 387, 388-391]. It is also seen that some of these studies [346, 379, 385] are based on OpenFlow. In addition, it is determined these studies consisted of general and comprehensive security studies in the first years and more specific subjects depending on the privatization of the areas in the following years.

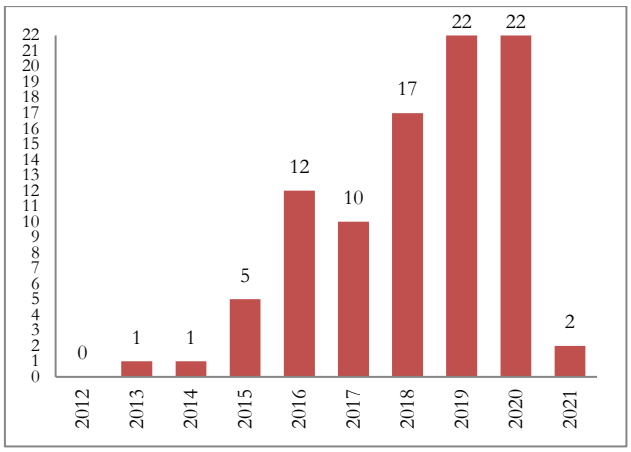


Fig. 5. Distribution of security survey studies on SDN by years.

3.3. SDWSN

The main purpose of a wireless sensor network (WSN) is to collect data in a particular area and to transmit this information to end-users. WSNs have several limitations, such as the sensor nodes have limited energy, the network topology has not stable, the updates are time-consuming due to a large number of sensor nodes, and the cost of network expansion and management.

Due to all these limitations, the implementation of SDN to WSNs has attracted a lot of attention in the research community over the past few years. Studies related to SDN in WSNs are carried out in relation to various aspects such as architecture, data aggregation and management, network topology, routing and localization, scheduling and energy consumption, data transmission and load balancing, and network security.

The papers carried out in the field of WSN and the distribution of the studies by years are given in Fig. 6.

Architecture, Data Aggregation and Management: [37, 310-311, 314-315, 317], SDN features are used to dynamically access the states of nodes for easy addition or removal of WSN nodes.

Network topology: [324], The SDN controller gets a dynamic view of the network and allows the network communication function normally.

Routing, Localization: [318] The SDN controller selects the route effectively to send the flow chart to the nodes.

Scheduling and energy consumption: [312] SDN can provide a good and effective programming algorithm for sending and receiving data, which can extend the life of nodes and thereby reduce network operating costs.

Transmission and network load: [47], SDN uses a load balancing mechanism to prevent network overload.

Network security: [309, 319-323], SDN combines encryption and network authentication due to the unique security requirements of WSNs thanks to its centralized control.

3.4. Artificial Intelligence

In recent years, it was seen that artificial intelligence methods are used to solve various network-related problems. These artificial intelligence techniques used in networks were adopted and used in the SDN paradigm. The integration of artificial intelligence techniques with the abstraction concept in the SDN paradigm has make network elements more adaptable. Recent studies show that the use of artificial intelligence which included deep learning and machine learning, approaches is become widespread in SDN. Figure 7 shows the distribution of survey studies on artificial intelligence by years. The survey studies are carried out, in-depth analysis of artificial intelligence studies on the subject of SDN [74-75], intrusion detection system using machine learning [239], machine learning based network security [234, 236-238], SDN routing optimization with machine learning comprehensive review of machine learning studies on SDN [44, 73, 235], and traffic classification and prediction on SDN with machine learning and deep learning techniques [122-123].

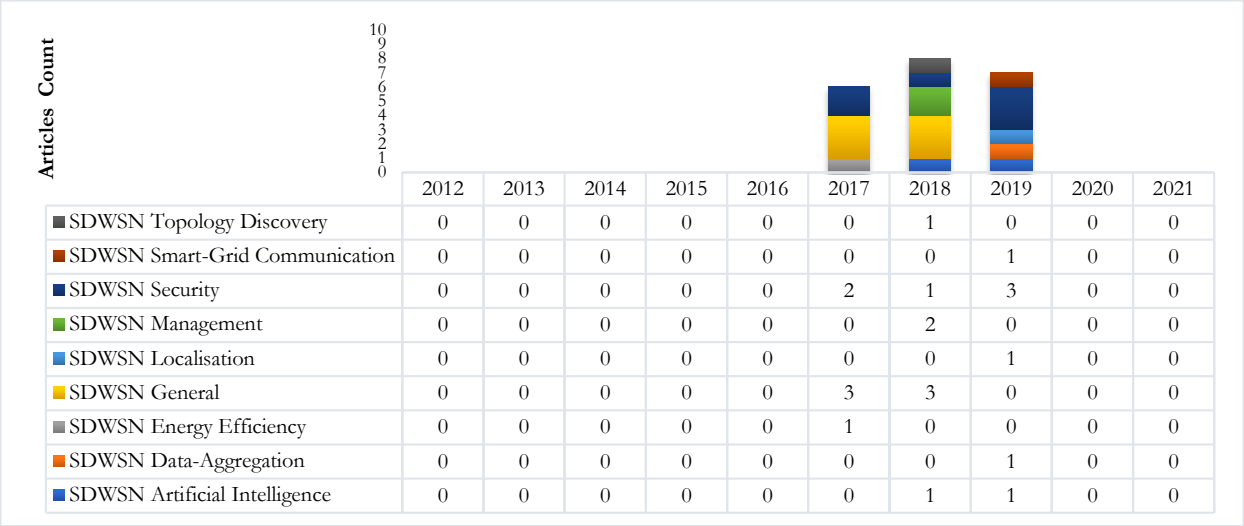
3.5. Network Function Virtualization (NFV)

Network Function Virtualization (NFV) is a new technology that targets network behavior execution as software, reduces costs, and has similar objectives as SDN, such as innovation and openness. NFV reduces energy consumption, device costs, operational complexity, and time to deploy updates by virtualizing network functions available on separate hardware devices and implementing these network functions as the software on commodity servers. They complement each other by defining SDN and NFV network behavior with software. Thus, the network control policy and network functions are implemented as software.

Figure 8 shows the distribution of survey studies on NFV by years. The survey studies are carried out on Virtual Network Function (VNF) Placement Problem [263], NFV-SDN architecture [21, 24, 45, 262, 265, 272], smart home [41], security features [43, 267], SDN-NFV-enabled 5G mobile network [11, 48, 57, 59-60, 243], cloud computing [264], optical network [271], traffic engineering [266], IoT [27, 130, 209], satellite network [268-269].

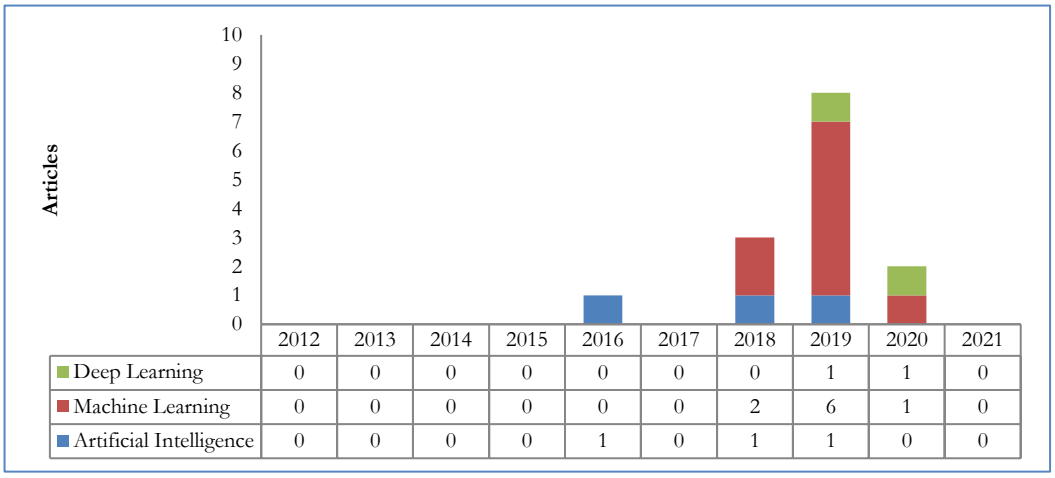
3.6. Internet of Things (IoT)

IoT is a system of devices that communicate and connect with each other thanks to various communication protocols and create a smart network by sharing information. There are some limitations to managing these devices, which generate a lot of data. To overcome these limitations, IoT is combined with new technologies such as SDN. SDN best meets the scalability, heterogeneity, and flexibility requirements of IoT. SDN and IoT are recognized in various areas such as smart grid settings, smart transportation, and smart homes.



	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
SDWSN Topology Discovery	0	0	0	0	0	0	1	0	0	0
SDWSN Smart-Grid Communication	0	0	0	0	0	0	0	1	0	0
SDWSN Security	0	0	0	0	0	2	1	3	0	0
SDWSN Management	0	0	0	0	0	0	2	0	0	0
SDWSN Localisation	0	0	0	0	0	0	0	1	0	0
SDWSN General	0	0	0	0	0	3	3	0	0	0
SDWSN Energy Efficiency	0	0	0	0	0	1	0	0	0	0
SDWSN Data-Aggregation	0	0	0	0	0	0	0	1	0	0
SDWSN Artificial Intelligence	0	0	0	0	0	0	1	1	0	0

Fig. 6. Distribution of WSN survey studies on SDN by years.



	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Deep Learning	0	0	0	0	0	0	0	1	1	0
Machine Learning	0	0	0	0	0	0	2	6	1	0
Artificial Intelligence	0	0	0	0	1	0	1	1	0	0

Fig. 7. Distribution of artificial intelligence survey studies on SDN by years.

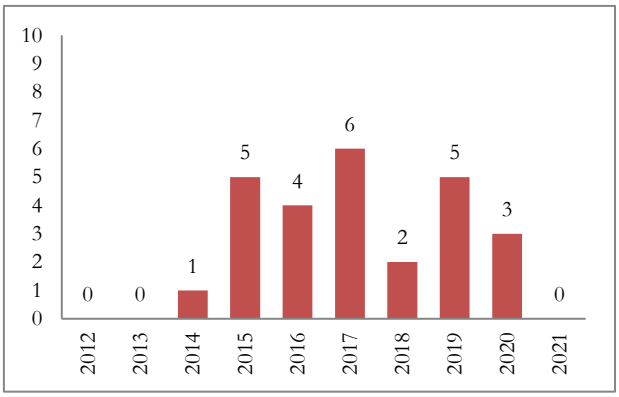


Fig. 8. Distribution of NFV survey studies on SDN by years

Figure 9 shows the distribution of survey studies on IoT by years. Studies on IoT in SDN are carried out, Wireless SDN research for IoT [222], network virtualization solutions for IoT [27, 209], in-depth analysis of IoT on SDN [29, 84, 206- 207, 213, 215], the security performance aspect of SDN on IoT [204-205, 208, 212, 214, 219, 220], improving IoT with SDN based solution [217], IoT architecture assisted with SDN [217], fog computing on IoT [144], SDN and NFV security mechanisms for IoT [43], cloud computing and edge computing over IoT [50, 83, 130], Big Data Issues in SDN Based IoT [76], SDN-Based IoT Challenges [210-211, 218], UAVs assessment in software-defined IoT networks [52].

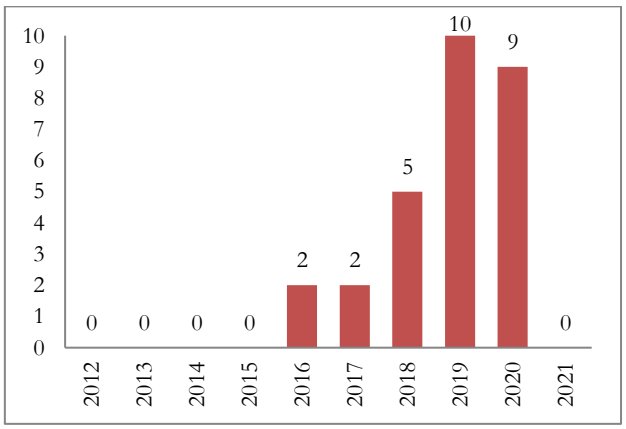


Fig. 9. Distribution of IoT survey studies on SDN by years.

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3.7. Controller Placement Problem (CPP)

In large networks, having a single controller on reliability and scalability is a major challenge. A large number of controllers are used to overcome this problem. When more than one controller is used in the network, the minimum number of controllers required, the distribution of the controllers on the network, and the number of devices connected to each controller are called the controller placement problem. Solving this problem makes the network more durable and increases its usability. To this end, most researchers focus on the problem of controller placement in SDN.

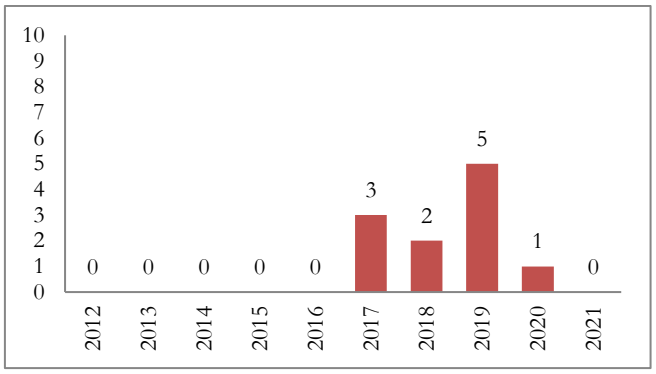

Fig. 10. Distribution of CPP survey studies on SDN by years.

CPP studies have increased in years as seen in Fig. 10. The surveys on SDN in CPP are realized, comprehensive analysis on CPP [46, 100, 104-106, 110-112] and feature selection strategies for the CPP [107-108].

3.8. 5G

The complexity and implementation of 5G's cellular network protocol require abstraction in cellular networks. SDN gives a different architectural approach for cellular networks, providing this abstraction. The SDN-based cellular architecture will be able to shape cellular communication in the IP connection. Recently, researchers, are focused on the benefits of the SDN concept over 5G.

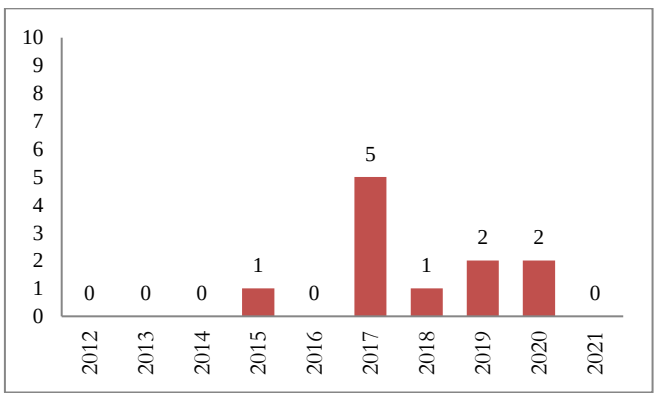

Fig. 11. Distribution of 5G survey studies on SDN by years.

Figure 11 shows the distribution of 5G survey studies on SDN by years. 5G studies on SDN are carried out, leveraging SDN for the 5G networks [61], emerging mobile computing in 5G [57], challenges SDN and NFV in 5G [59-60], comprehensive analysis on 5G for SDN [53-56, 58] network slicing for 5G with SDN and NFV [11, 48].

3.9. Load Balancing

Load balancing is a method of distributing the load across network components to optimize network performance. Load balancing techniques, algorithms, and developed strategies help both end-users and service providers to transfer or assign a load to increase efficiency. Load balancing helps to predict this bottleneck before a traffic bottleneck occurs, and today it is frequently encountered in SDN studies with the increasing amount of data. Within the scope of this study, the distribution of load balancing survey studies performed in different layers of SDN [78, 114, 132, 142, 225- 233] by years is given in Fig. 12. As can be seen in Fig. 12, load balancing studies have increased in recent years.

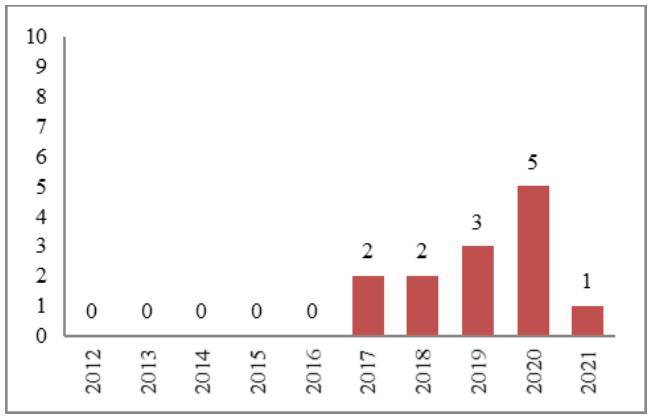

Fig. 12. Distribution of Load-Balancing survey studies on SDN by years.

4. Further Research Directions

After conducting a systematic review of survey studies, several potential research directions and corresponding subtopics have emerged within the domain of SDN, which are briefly explained below.

1) Security in SDN:

In the field of SDN security, numerous promising research avenues exist. Researchers can explore the application of SDN-based security solutions in hybrid network environments to enhance protection against evolving threats. Additionally, the adaptive selection of security approaches presents an opportunity to dynamically respond to emerging risks. Evaluating the effectiveness and practicality of these innovative security mechanisms in comparison to traditional solutions is essential. Furthermore, integrating SDN-based security with new and emerging technologies can enhance network reliability and resilience. Lastly, exploring advanced

security paradigms within SDN to secure new technologies represents a significant frontier.

2) Content and Performance Placement:

The field of content and performance placement within SDN holds substantial potential for future research. One avenue involves developing efficient traffic engineering strategies to optimize network resource utilization. Tailored load balancing techniques for SDN environments can ensure more even traffic distribution. There is also room for designing algorithms that consider energy efficiency and cost sensitivity. Creating flexible and reliable network architectures is vital, providing networks with the agility to adapt to changing demands. Researchers can also explore machine learning-based strategies for content and performance placement, offering innovative approaches to content and performance management. Finally, evaluating network topologies and scaling strategies remains crucial for achieving efficient and scalable SDN deployments.

3) 5G and 6G:

As the transition from 5G to forthcoming 6G networks approaches, various research challenges and opportunities emerge. Addressing the issues related to mm-wave and THz spectrum ranges is critical for harnessing these technologies. Ensuring universal channel availability, especially in dense urban environments, presents challenges that require innovative solutions. Efforts to enhance Quality of Experience (QoE) in 5G and 6G networks through standardization are pivotal. Improving energy efficiency while accommodating diverse applications is another important aspect. Enhancing mobility and routing to meet future network demands represents a promising area of exploration. Interoperability challenges and proactive troubleshooting of security issues will also be paramount.

4) Load Balancing in SDN:

Load balancing offers a rich field for future research in SDN. There is a need for the development of load balancing applications that can effectively alleviate the high controller load on the data plane, ensuring efficient network operations. Regulating dynamic load balancing techniques for multiple controllers in SDN architectures is an interesting challenge. Utilizing load balancing strategies to enhance the efficiency of hierarchical controllers can lead to more scalable and responsive networks. Realizing network virtualization across multiple controllers can open new possibilities for resource optimization. Additionally, regulating controller placement techniques is crucial for achieving optimal network performance. Furthermore, minimizing setup latency through the development of efficient flow rules and designing low-latency load balancing techniques for SD-WAN applications can substantially improve network responsiveness. Finally, energy-efficient load balancing techniques are essential for sustainability and cost-effectiveness in SDN infrastructures.

5) Internet of Things (IoT):

IoT presents a rich field for future research within SDN. Ensuring dynamic changes in routing rules to accommodate IoT device mobility is a critical area of exploration. Optimizing traffic flow management in IoT networks can enhance their efficiency and responsiveness. Addressing challenges related to controller positioning and minimizing delays due to device movements is crucial for smooth IoT operations. Resolving security and privacy concerns in IoT deployments is paramount, ensuring the protection of sensitive data and user privacy. Besides, enhancing interoperability among diverse IoT devices is essential for seamless communication. Finally, achieving reliable and efficient data transfer for mobile IoT devices, often with varying data volumes, presents an ongoing challenge deserving of innovative solutions.

5. Conclusion

This paper presents a systematic taxonomy for the literature on SDN survey studies. In this taxonomy, 442 survey articles, comprising 298 journal articles, 135 conference proceedings, and 9 book chapters published between 2012 and 2021, are examined. It is noteworthy that the number of survey papers has significantly increased over the years. The academic journals are arranged in descending order based on the number of survey articles published, and the quartile score of each journal is provided. 268 of the 298 journal proceedings articles are ranked in the Q1, Q2, Q3, or Q4 quartiles. The quartile ranks of these 268 journals are specified. Out of the 268 journals, 155 fall into the Q1 quartile, 55 into the Q2 quartile, 29 into the in Q3 quartile, and 29 into the Q4 quartile. Additionally, 30 out of the 298 articles are listed but do not appear in the Q1-Q4 quartiles.

Following the analysis of survey articles citations, their influence in the field of SDN is introduced. The first 30 most cited articles according to Web of Science, Google Scholar, and Scopus citation rankings are listed. Furthermore, the 5 highest-cited articles from the years 2013 to 2020 based on the citation rankings of Web of Science are provided. The distribution of topics of survey studies by year is illustrated, and the most frequently occurring keywords and their counts in the survey articles are presented. The most frequent keywords, in descending order, include General, Security, Wireless SDN, IoT, 5G, CPP, Load Balancing, Vehicular Ad-Hoc Network, Cloud Computing, AI, and NFV.

In conclusion, this paper categorizes a wide range of contributions from survey studies, presents an epistemological review of the subject, and represents the first-ever taxonomic review paper in SDN across various dimensions.

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