Available online at www.sciencedirect.com

ScienceDirect

Procedia Computer Science 64 (2015) 552 – 561

Procedia
Computer Science

Conference on ENTERprise Information Systems / International Conference on Project MANagement / Conference on Health and Social Care Information Systems and Technologies, CENTERIS / ProjMAN / HCist 2015 October 7-9, 2015

A Literature Review on Challenges and Effects of Software Defined Networking

Raphael Horvath[a], Dietmar Nedbal[a,]*, Mark Stieninger[a]

[a]*University of Applied Sciences Upper Austria, Wehrgrabengasse 1-3, 4400 Steyr, Austria*

Abstract

Network technologies have always been a crucial part of success for technologies like cloud computing. But due to the slow development of a scalable IT infrastructure, this can lead to issues in competitiveness. Software defined networking (SDN) can thereby counteract such issues by giving new functions to the whole network topology. With SDN, administrators have the possibility to abstract the underlying network infrastructure for applications and network services. The paper reports on the main outcomes of a systematic literature review on challenges and effects of SDN. It shows that most papers address the implementation of software defined networking as a challenge, including factors like vendor lock-in and the general risk of changing traditional network architectures. Attention is also given to security issues arising with software defined networks and the permanent high demand from the end-user combined with the fear of changing traditional networks. Issues dealing with specialized know-how were identified as another challenge category. Effects of SDN are discussed by defining unique features of SDN like decoupling hardware from the software and the global view of the whole network architecture. SDN furthermore affects the management of the network, including changes in deployment of policies, the programmability and maintenance of the network. Economic factors, such as cost efficiency and reduction of costs, are also discussed.

Peer-review under responsibility of SciKA - Association for Promotion and Dissemination of Scientific Knowledge

Keywords: cloud computing; software defined networking; SDN; software defined network; literature review

* Corresponding author. Tel.: +43-50804-33415; fax: +43-50804-33499.
E-mail address: dietmar.nedbal@fh-steyr.at

1877-0509
Peer-review under responsibility of SciKA - Association for Promotion and Dissemination of Scientific Knowledge
doi:10.1016/j.procs.2015.08.563

1. Introduction

Cloud computing as an alternative to traditional computing technology has become one of the most important ICT topics during the last couple of years[1,2]. In a need to improve the performance of organizations by ICT, cloud computing has already changed their information infrastructure and associated business processes as well as business models[3].

Cloud services in general are evoking new challenges for organizations, such as a higher quality of service or high-security networking. To fulfil the increasing demands of end-users, enhanced virtualization technologies are becoming crucial for success. Throughout this paradigm providers require new solutions to manage these demands. Services from big cloud providers, like Amazon EC2 or Microsoft Azure, are mostly deployed to single enterprises of all sizes and to private customers as well, which can increase the challenge of distributing and controlling the needed resources at the right time. The tremendous increase in demand of cloud services from the view of the customer comes along with energy-efficiency and high-security needs[4].

The currently most widely used definition[5] of cloud computing, the NIST definition of cloud computing[6], distinguishes between the four deployment models (i) private cloud, (ii) public cloud, (iii) community cloud, and (iv) hybrid cloud to describe cloud computing. In an addition to that, the novel term “inter-cloud” stands for a large scale evolutionary leap based on the former cloud deployment models. It can be described as a “cloud of clouds” or a “network of networks”. The NIST definition of cloud computing names rapid elasticity as a key characteristic of cloud computing which makes it suggestive of unlimited capabilities available for provision within one cloud. Increased utilization ratio however leads to imminent shortages which can be counteracted by resource pooling with other clouds. In order to fulfil the claim of the NIST definition of cloud computing for high flexibility, rapid scalability, and optimized resource usage, a more advanced information architecture is needed. As a novel and innovative approach, a software defined cloud infrastructure seems to be a promising candidate to provide proper solutions for the following trends and domains[7,8]:

- *Cloud services:* Organizational units that have already adopted public and private cloud services now want self-service provisioning of their applications, infrastructure, and other ICT resources. Taking into account additional security, compliance, and auditing requirements, along with business reorganizations, consolidations, and mergers, this is a complex challenge.
- *Consumerization of ICT:* ICT departments are increasingly confronted with employees using their personal devices such as smartphones, tablets, and notebooks to access corporate applications while on the other side they have to secure corporate data and protect intellectual property. This trend usually is referred to as bring your own device (BYOD).
- *Changing traffic patterns:* Today’s applications access different servers across various enterprise data centers before returning the data to the end users device. This creates a lot of additional machine-to-machine traffic that has to be transferred to connecting devices from anywhere, at any time.
- *Big data:* Processing large scale datasets on thousands of distributed servers demands more bandwidth. Additional network capacity is needed within and between the enterprise data centers, distributed across different locations.
- *Internet of Things:* Waiting in the wings, the Internet of Things (IoT) will shortly demand novel infrastructure architectures as well and even more dynamic flexibility and scalability to process the expected bulk of data and to manage its distributed origins.

With these constantly increasing requirements organizations have to be open-minded and reconsider their way of managing ICT infrastructure to stay profitable and cost-efficient. Network technology has therefore become a crucial part of success for cloud technologies[9], but due to the slow development of a true scalable ICT infrastructure, this can lead to issues in competitiveness[4].

Software defined networking (SDN) can counteract issues arising from the network by giving new functions to the whole network topology and therefore “*has the potential to enable ongoing network innovation and enable the network as a programmable, pluggable component of the larger cloud infrastructure*”[10]. It “*provides the network operators and data centres to flexibly manage their networking equipment using software running on external* *servers*"[11]. The Open Networking Foundation describes software defined networking as dynamic, manageable, cost-effective, and adaptable emerging network architecture, which is needed for today's complexity of applications[7]. Administrators have the possibility to abstract the underlying network infrastructure for applications and network services. The network management, which is usually implemented in software, is decoupled from the data tier which enables cloud services to self-adapt according to changes in the network context[12]. SDN enables organizations to gain better insight of where which workloads and data reside. Utilizing this knowledge can be used to make better decisions where data should reside and thus eliminate major security concerns of public clouds previously discussed.

The main goal of this paper is to point out challenges and effects of SDN related to current network structures via a systematic literature review. In a first step the paper covers the approach of the literature review followed by an overview of the main results (section 2). Section 3 discusses the outcomes of the literature review in depth. Finally, conclusion is drawn in section 4.

2. Literature Review: Software Defined Networking

A literature review essentially examines relevant literature for a specific field of study. It creates a stable basis by examining what is already known about a chosen topic[13]. As a result, a literature review opens new approaches for further studies and progresses in the concerning field of research[14]. The review has its main goal in identifying the used methods and concepts for effects and challenges in SDN development.

2.1. Approach

Recognized and approved journals and databases for both information system and computer science research were used for the literature research. The used databases and journals are comprised of ACM (dl.acm.org), AISeL (aisel.aisnet.org), IEEE (ieeexplore.ieee.org), Science Direct (www.sciencedirect.com) and Springer Link (link.springer.com). The time range of the search field was limited to years starting at 2010. Search queries on the time period before the year 2010 did not lead to relevant results, as the term software defined networking and especially its abbreviation SDN was used for other topics. All search queries were attempted between the 1st of June and 15th of June 2014.

The defined keywords reflected the main purpose of the literature review. Therefore, the following keywords were defined and used to search for relevant articles and proceedings: (i) sdn challenge, (ii) "software defined networking" challenge, (iii) sdn impact, (iv) "software defined networking" impact, (v) sdn evolution, (vi) "software defined networking" evolution.

The main task of the next step was to find relevant articles for the literature review. The chosen approach was to scan all abstracts from the published articles, which were obtained by searching using the defined keywords. After scanning the abstracts and deciding whether they were relevant or not, the chosen articles were saved for the next step.

The initial search results of each database with the defined keywords were as follows ("found" means the number of all articles returned by the queries and "relevant" those papers chosen to investigate in detail): ACM (found: 824, relevant: 11), AISeL (found: 50, relevant: 0), IEEE (found: 1290, relevant: 33), Science Direct (found: 241, relevant: 12) (www.sciencedirect.com) and Springer Link (found: 108, relevant: 5). The high number of identified articles versus relevant articles exists for several reasons. The keywords were searched individually (i.e. each database was queried 6 times). Many articles appeared several times during the search query, as various keywords provided overlapping results. These doublets were removed. Second, most of the articles discussed and defined advanced statistical and mathematical technologies not relevant to answering the research question. Furthermore, several articles covered a completely different topic since SDN also can be an abbreviation for other topics like "Supply and Demand Networks" or "Shareware Distribution Network". In order to evaluate whether the articles were relevant or not, every title and abstract of the found articles was scanned and critically evaluated as to whether the content would be helpful for the research focus. In total, 61 articles were defined as relevant.

In the next step every single one of the 61 articles was analyzed in depth and collected in a first concept matrix. Furthermore, the used methods, the main idea, the outcome, and the final classification – if relevant or not – were recorded in that matrix. Furthermore, during transferring of the articles into the concept matrix, an additional detailed selection process took place. Thus, a few articles were also classified as not relevant. The reason being that the abstract defined "software defined networking" as the main part of the article, but largely covered areas not relevant for the review. In the end, 44 articles were included in the literature review. The final concept matrix is provided in the appendix. Finally, based on the final concept matrix, categories and concepts were defined and are described in detail in the following.

2.2. Main Results of the Literature Review

The review revealed that the demand and need for research on the topic of SDN combined with challenges and effects increased since the year 2011. With no relevant article found in 2010 and one relevant article found in 2011, the first increase was evident in the year 2012 with seven relevant articles. Already 22 articles deal with challenges and effects of SDN in the year 2013 and in the first half of the year 2014 there were again 14 articles on that topic. The temporal analysis shows that SDN is gaining relevance with further research and analytical approaches being expected within the following years.

Figure 1 shows an overview of the identified challenges and effects of SDN. Most papers address the implementation as a challenge. Factors, like vendor-lock-in effects and the high risk of changing traditional network architectures, are included in this category, and discussed and researched most often. The second highest in terms of attention given is the category of demand. Included in this category are security issues arising with software defined networking and the permanent high demand from the end-user combined with the fear of changing traditional networks. The third category describes the topic of know-how existing for software defined networking. Administrating and controlling software defined networks with the existing staff and the overload arising from this were subsumed in this category.

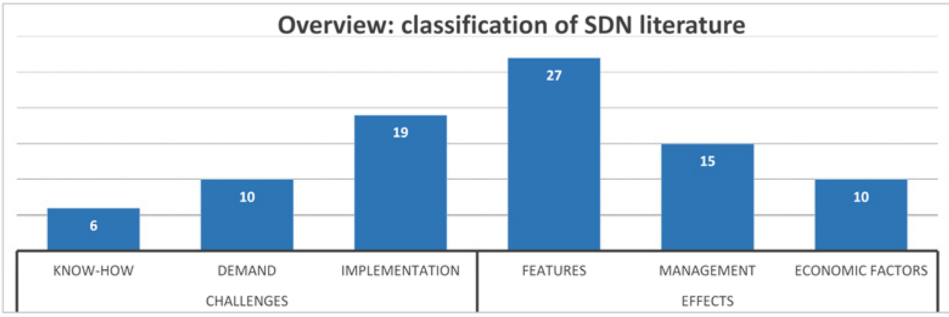

Fig. 1. Overview of number of papers dealing with challenges and effects of SDN.

Figure 1 furthermore shows that the unique features of software defined networking are discussed the most in the articles analyzed. Elements, like decoupling hardware from the software and the global view of the whole network architecture, take place in this category. The second category – management – is an important part when describing effects of software defined networks compared with traditional networks. Easier deployment of policies, the programmability and maintenance of the network are included in this main category. The last category describes the economic factors, such as cost efficiency and reduction of costs needed for specific and skilled staff. These trends show that current research is more focused on technical and scientific consideration.

3. Discussion of Results

This section discusses the challenges and effects identified through the systematic literature review in depth.

3.1. Software Defined Networking: Challenge – Know-How

The literature recognizes that software defined networking faces a big challenge concerning current know-how existing in data centers. According to Caraguay et al., integrating SDN in an enterprise needs an estimation of the needed numbers of controllers by determining the topology and the localization of these controllers. Furthermore, a lack of know-how can result in high security risk since the centralized controller of a software defined network can be very vulnerable compared to traditional networks[15]. Patouni et al. also identify similar challenges when such architecture is handled by unskilled staff. They mention that preserving the network operation requires a migration plan and a well-considered roadmap to avoid having single points of failures[16]. Casado et al. acknowledge that software defined networking could have the potential to meet challenges existing in traditional networks, like vendor lock-in or complex management. Nevertheless, this technology has not yet matured so that current operators are faced with high complexity instead of easy management and easy building of network architecture[17]. Another point of view states that software defined networking may currently be a well-established standard in certain enterprises and industries, but applying this technology still requires a completely new pool of know-how when it comes to architectural updates on the operators' side and to additional overhead meeting current devices in current networks[18,19]. Specific examples of required know-how are the deployment of middle boxes in choke points and managing of traffic isolation in networks[20]. Thus, Caraguay et al. assume software defined networking is not easily transferable to smaller networks with a lack of skilled staff since the decoupling approach was mainly built for huge enterprises. Thereof unexpected interaction with other deployed networks can arise causing an increase of the broadcast traffic emitted from non OpenFlow compatible devices[15].

3.2. Software Defined Networking: Challenge – increasing Demand

Akyildiz et al. identify several challenges concerning increasing demand when it comes to new technologies. For example, the need for a suitable and specific service for several traffic types, such as video conferencing or web browsing in a very short time range, and further the need for improved resource utilization for higher system performance of the rapid growth of cloud computing[21]. Galis et al. agree with these points by mentioning that the user's demand is never ending but instead rapidly increasing which makes it necessary to think about software defined networking[22]. Regardless of the high demand, today's coupling between infrastructure and architecture in traditional networks means a fundamental change in the current topology, which comes along with high costs for vendors as well as companies. New requirements for mobility, server virtualization and cloud computing need to meet the increasing demand – especially when it comes to quality of service or security issues. Therefore, software defined networking still lacks and the centralized controller does not yet fulfil the demand because of negative compromised resilience of the whole network[23,24,15]. According to Bhattacharya & Das[25], the topic of quality of service is one of the core elements related to the internet and has to handle fast changing requirements and dynamically distributed policies. Throughout the field of software defined networking, providers now have a global view over the whole architecture and can therefore handle the mentioned challenges. However, the usage of existing equipment cannot meet the increasing demand, further necessitating an expensive investment in new equipment. Raghavan et al. describe this as the current embargo to further development of software defined networking[24]. Patouni et al. argue that during the course of the huge increase of the variety of proprietary hardware appliances, great challenges have occurred for management when trying to launch new network services. In more detail they mention the Internet of Things as an additional factor when it comes to increasing requirements. Even if software defined networking is developing into a promising solution, there are still challenges, like quickness for automation or isolation which ensure high performance when it comes to the mentioned demands[16]. On the basis of a concrete example, Costa-Requena outlines software defined networking in LTE mobile networks. The huge demand and increase of devices makes it necessary to invest in new technologies, but software defined networking only "seems" to be a key enabler in developing new telecommunication infrastructure[26].

3.3. Software Defined Networking: Challenge – Implementation

The implementation of software defined networking in traditional networks is recognized as one of the main challenges. Despite the successes so far, SDN implementation is still in an early stage of development[10]. The common consensus among the authors defines the complexity of the new technology as central causes. Existing research and industry solutions could resolve only some of these problems dealing with performance, scalability, security, and/or interoperability[4]. Galis et al. identify the problem of how to implement new technology without reinventing the whole architecture with its aspects and related components[22]. This opinion goes along with Cahn et al., who describe the long implementation schedule as the biggest disadvantage[27]. The main aspects of the challenge consist of unexpected interaction with other deployed networks, integration with legacy networks, which do not support the OpenFlow protocol, fundamental errors when emulating software defined networking beyond certain limits, architectural updates and deep changes in inter-domain routing protocols, service models and operating procedures[15,28,29,18]. Lu et al.[30] and Caraguay et al.[15] identify, in addition to technical challenges, the financial limitations of enterprises, since software defined networking needs a full deployment of "SDN-enabled" network switches and an intense re-engineering of the whole network topology. The risk of implementing software defined networking (even if there are dozens of benefits) is currently too high for most companies and enterprises. In this case security issues take on an important role, since software defined networking is very vulnerable and the firewall can be bypassed by adding deliberated flow tables[31,32,15,33]. But even if software defined networking faces great challenges at the point of implementation, the advantages that occur afterwards (like scalability and reliability) justify an approach and further experiments with applications for enhancing data center network management[34,35].

3.4. Software Defined Networking: Effect – Features

Software defined networking consists of several new features compared to traditional networks. The most common and most often mentioned feature in the literature is the possibility of decoupling the forwarding plane from the data plane, leading to several abstraction layers[36,37,10,38]. Azodolmolky et al. describe this as revolutionary when comparing tight traditional network models[39,11]. This circumstance results in a programmability of the data plane (which enables manipulation of the forwarding tables), a customization of networks (such as data center interconnections) and centralized control decisions due to a global view over the whole network[40,41,21,42,43]. Natarajan et al. complement this by describing the OpenFlow protocol as an increase of network visibility[44]. Kirkpatrick also recognizes the given API as a feature, delivered by software defined networking, to handle applications (like e-mail or telephone applications) easily over the whole network[45]. Dynamic, demand-based network segmentation and utilization are furthermore defined as crucial key features of software defined networking[45,46]. An additional optimization of the header information by using dynamic flows rather than static routing significantly reduces the overhead on per byte transfer[47]. Dely et al. report on a SDN-based architecture for optimizing handover mechanisms in wireless LANs[48]. Vissicchio et al. summarize SDN by defining such features as a new architecture, which provides the possibility of controlling the whole network structure with the benefits of an innovative and improved management[49]. Azodolmolky et al. define the key features in seven points, which accompany the major features found in the literature[39].

3.5. Software Defined Networking: Effect – Management

The main goal of effective network management is to handle a series of methods, tools and activities to finally ensure high quality for the end user. Software defined networking thereby realizes this by several factors, such as an increase of network utilization and simplifying the management by software controlled hardware[50,51,41]. Today's challenges include the rapid growth of cloud computing and the need for a suitable and specific service for traffic types in a short time range – therefore, as Akyildiz et al. mention, software defined networking offers a global view over the whole topology and resulting in efficient management[21]. Because of this increasing demand there is a need for easy management through a separate common management plane[52,39]. Throughout the impact of SDN, operators are going to face even more challenges, such as increased storage. The future network infrastructure will consist of a huge number of resources, such as virtualization, allocation and migration. A new ecosystem will be created where management with software defined networking plays a significant role. Wee summarizes SDN as the biggest innovation in networking in the past two decades by uniting the basic principles of network programmability, automating and orchestrating[41]. In contrast to traditional networks, a software defined network is not dependent on "dumb" devices making decisions, but is based on a centralized controller which allows rapid deployment and globally based decisions. In this case, software defined networking will have a fundamental and positive effect.

3.6. Software Defined Networking: Effect – Economic Factors

Software defined networking offers great opportunities to increase efficiency while at the same time reducing costs and complexity[53,54]. Today's cloud computing demands are exploding, and as a result less energy consumption and high security networking is needed[21,4]. Compared to traditional networks, Lombardo et al. identify high potential for dynamic allocation of network functions over network nodes, but the process of testing, experimenting and launching is still too time consuming and is not compatible with business needs[55]. Casado et al. mention at this point that current networks are too expensive and too complicated to manage[17].

4. Conclusion

Software defined networking is seen as an evolutionary paradigm shift, but still faces several challenges. The covered areas of challenges and effects provide a general view of what may slow down further development and what is possible when the technology is integrated successfully.

A certain lack of know-how, combined with high complexity when it comes to integration into traditional networks, are main reasons for a delayed diffusion of the technology. Furthermore, the analyzed papers mostly describe software defined networking on a very detailed mathematical and technological basis, making it very hard for enterprises and organizations to assess if the technology can have a specific business impact (e.g. on increasing efficiency or reducing costs). Nevertheless, the steady increase of users and requirements leave providers faced with the need to rethink the usage of current network technologies in order to stay competitive and profitable. As the literature review has revealed, the separation of the control and data plane offers great benefits, such as easier management, enhanced features, like dynamic deployment of virtual networks as well as economic factors. Besides outlining the technical aspects these benefits should play an important role in further research, especially in the IS domain.

Appendix A. Literature Review Concept Matrix

Table 1. Literature Review Concept Matrix

Ref #	Author(s), year	know-how	demand	implemen-tation	features	manage-ment	economic factors
21	Akyildiz et al., 2014		x		x	x	x
11	Azodolmolky et al., 2013				x		
39	Azodolmolky et al., 2013				x	x	
28	Bennesby et al., 2012			x	x		
25	Bhattacharya & Das, 2013		x	x			
27	Cahn et al., 2013			x	x		
15	Caraguay et al., 2012	x	x	x		x	
17	Casado et al., 2012	x					x
42	Conti et al., 2011				x		
26	Costa-Requena, 2014		x			x	
48	Dely et al., 2013				x		
34	Dixit et al., 2013			x	x		

22	Galis et al., 2013		x	x	x		
19	Gelberger et al., 2013	x					x
38	Gorja & Kurapati, 2014				x		
35	Gupta et al., 2013			x	x	x	
53	Hampel et al., 2013					x	x
37	Idoudi & Elbiaze, 2013				x		
36	Jarraya et al., 2014				x		
23	Jin & Nicol, 2013		x		x	x	
47	Kannan & Banerjee, 2012				x		
45	Kirkpatrick, 2013		x		x	x	
10	Kobayashi et al., 2014			x	x		
40	Kuklinski, 2014			x	x		
20	Lara et al., 2014	x			x	x	
55	Lombardo et al., 2014						x
30	Lu et al., 2013			x			
52	Manzalini & Minerva, 2013				x	x	
18	Monteleone & Paglierani, 2013	x		x			x
44	Natarajan et al., 2013				x		
54	Naudts et al., 2012		x			x	x
16	Patouni et al., 2013	x	x	x			
8	Qin et al., 2014				x		
24	Raghavan et al., 2012		x				x
32	Raza et al., 2014			x			x
29	Roy et al., 2013			x	x		
33	Scott-Hayward et al., 2013			x			
4	Sezer et al., 2013			x			x
49	Vissicchio et al., 2014			x	x	x	
31	Wang et al., 2013			x		x	
41	Wee, 2014			x	x	x	
43	Wu et al., 2014				x		
50	Xu et al., 2014					x	
46	Zinner et al., 2014				x		
	Total:	**6**	**10**	**19**	**27**	**15**	**10**

References

1. Park SC, Ryoo SY. An empirical investigation of end-users' switching toward cloud computing: A two factor theory perspective. *Computers in Human Behavior* 2013; **29**(1):160–70.
2. Won K. Cloud Computing: Today and Tomorrow. *Journal of Object Technology* 2009(8):65–72.
3. Wu W. Developing an explorative model for SaaS adoption. *Expert Systems with Applications* 2011; **38**(12):15057–64.
4. Sezer S, Scott-Hayward S, Chouhan PK, Fraser B, Lake D, Finnegan J, Viljoen N, Miller M, Rao N. Are We Ready for SDN? Implementation Challenges for Software-Defined Networks. *IEEE Communications Magazine* 2013:36–43.
5. Stieninger M, Nedbal D. Characteristics of Cloud Computing in the Business Context: A Systematic Literature Review. *Glob J Flex Syst Manag* 2014; **15**(1):59–68.
6. Mell P, Grance T. *The NIST definition of cloud computing*; 2011.
7. Open Networking Foundation. *Software-Defined Networking: The New Norm for Networks (ONF White Paper)*; 2012.

8. Qin Z, Denker G, Giannelli C, Bellavista P, Venkatasubramanian N. A Software Defined Networking Architecture for the Internet-of-Things. *IEEE Network Operations and Management Symposium (NOMS)* 2014.
9. Guo Z, Su M, Xu Y, Duan Z, Wang L, Hui S, Chao, H. Jonathan. Improving the performance of load balancing in software-defined networks through load variance-based synchronization. *Communications and Networking in the Cloud* 2014; **68**(0):95–109.
10. Kobayashi M, Seetharaman S, Parulkar G, Appenzeller G, Little J, van Reijendam J, Weissmann P, McKeown N. Maturing of OpenFlow and Software-defined Networking through deployments. *Computer Networks* 2014; **61**:151–75.
11. Azodolmolky S, Wieder P, Yahyapour R. SDN-Based Cloud Computing Networking. *ICTON* 2013.
12. Rubio-Loyola J, Galis A, Astorga A, Serrat J, Lefevre L, Fischer A, Paler A, Meer H. Scalable service deployment on software-defined networks. *IEEE Commun. Mag.* 2011; **49**(12):84–93.
13. Levy Y, Ellis TJ. A Systems Approach to Conduct an Effective Literature Review in Support of Information Systems Research. *Informing Science Journal* 2006; **9**:181–212.
14. Webster J, Watson RT. Analyzing the past to prepare for the future: writing a literature review. *MIS Quarterly* 2002; **26**(2):xiii–xxiii.
15. Caraguay ALV, Lopez LIB, Villalba LJG. Evolution and Challenges of Software Defined Networking. *IEEE Communications Magazine* 2012.
16. Patouni E, Merentitis A, Panagiotopoulos P, Glentis A, Alonistioti N. Network Virtualisation Trends: Virtually Anything Is Possible by Connecting the Unconnected. *IEEE SDN for Future Networks and Services (SDN4FNS)* 2013.
17. Casado M, Koponen T, Shenker S, Tootoonchian A. Fabric: A retrospective on evolving SDN. *ACM HotSDN* 2012.
18. Monteleone G, Paglierani P. Session Border Controller Virtualization Towards "Service-Defined" Networks Based on NFV and SDN. *IEEE SDN for Future Networks and Services (SDN4FNS)* 2013:1–7.
19. Gelberger A, Yemini N, Giladi R. Performance Analysis of Software-Defined Networking (SDN). *IEEE 21st International Symposium on Modeling, Analysis & Simulation of Computer and Telecommunication Systems (MASCOTS)* 2013:389–93.
20. Lara A, Kolasani A, Ramamurthy B. Network Innovation using OpenFlow: A Survey. *IEEE Communications Surveys & Tutorials* 2014; **16**(1):493–512.
21. Akyildiz IF, Lee A, Wang P, Luo M, Chou W. A roadmap for traffic engineering in SDN-OpenFlow networks. *Computer Networks* 2014; **71**:1–30.
22. Galis A, Clayman S, Mamatas L, Rubio Loyola J, Manzalini A, Kuklinski S, Serrat J, Zahariadis T. Softwarization of Future Networks and Services - Programmable Enabled Networks as Next Generation Software Defined Networks. *IEEE SDN for Future Networks and Services (SDN4FNS)* 2013.
23. Jin D, Nicol DM. Parallel simulation of software defined networks. *SIGSIM-PADS'13,* 2013:91–102.
24. Raghavan B, Koponen T, Ghodsi A, Casado M, Ratnasamy S, Shenker S. Software-defined internet architecture: decoupling architecture from infrastructure. *ACM Hotnets '12* 2012:43–8.
25. Bhattacharya B, Das D. SDN based Architecture for QoS Enabled Services Across Networks with Dynamic Service Level Agreement. *IEEE ANTS* 2013.
26. Costa-Requena J. SDN integration in LTE mobile backhaul networks. *IEEE ICOIN* 2014:264–9.
27. Cahn A, Hoyos J, Hulse M, Keller E. Software-Defined Energy Communication Networks: From Substation Automation to Future Smart Grids. *IEEE SmartGridComm 2013 Symposium - Smart Grid Services and Management Models* 2013:558–63.
28. Bennesby R, Fonseca P, Mota E, Passito A. An inter-AS routing component for software-defined networks. Network Operations and Management Symposium (NOMS), 2012 IEEE 2012:138–45.
29. Roy A, Yocum K, Snoeren AC. Challenges in the emulation of large scale software defined networks. *ACM APSys '13* 2013.
30. Lu H, Arora N, Zhang H, Lumezanu C, Rhee J, Jiang G. HybNET: Network Manager for a Hybrid Network Infrastructure. *Middleware 2013 Industry Track* 2013.
31. Wang J, Wang Y, Hu H, Sun Q, Shi H, Zeng L. Towards a Security-Enhanced Firewall Application for OpenFlow Networks. *Springer LNCS 8300, CSS* 2013:92–103.
32. Raza MH, Sivakumar SC, Nafarieh A, Robertson B. A Comparison of Software Defined Network (SDN) Implementation Strategies. *Procedia Computer Science* 2014; **32**:1050–5.
33. Scott-Hayward S, O'Callaghan G, Sezer S. SDN Security: A Survey. *IEEE SDN for Future Networks and Services (SDN4FNS)* 2013:56–62.
34. Dixit A, Hao F, Mukherjee S, Lakshman TV, Kompella R. Towards an elastic distributed SDN controller. *ACM HotSDN* 2013:7–12.
35. Gupta M, Sommers J, Barford P. Fast, accurate simulation for SDN prototyping. *ACM HotSDN* 2013:31–6.
36. Jarraya Y, Madi T, Debbabi M. A Survey and a Layered Taxonomy of Software-Defined Networking. *IEEE Commun. Surv. Tutorials* 2014; **16**(4):1955–80.
37. Idoudi K, Elbiaze H. Enhancing Open Flow to Enable Multilayer Networking. *ICTON* 2013.
38. Gorja P, Kurapati R. Extending open vSwitch to L4-L7 service aware OpenFlow switch. *Advance Computing Conference (IACC), 2014 IEEE International* 2014:343–7.
39. Azodolmolky S, Wieder P, Yahyapour R. Cloud Computing Networking: Challenges and Opportunities for Innovations. *IEEE Communications Magazine* 2013:54–62.
40. Kuklinski S. Programmable Management Framework for Evolved SDN. *IEEE Network Operations and Management Symposium (NOMS)* 2014.
41. Wee S. The Next Generation of Networked Experiences. *ISSCC* 2014.
42. Conti M, Chong S, Fdida S, Jia W, Karl H, Lin Y, Mähönen P, Maier M, Molva R, Uhlig S, Zukerman M. Research challenges towards the Future Internet. *Computer Communications* 2011; **34**(18):2115–34.

43. Wu J, Wosinska L, Shen G, Spadaro S. Optical Networks Control and Management. *Journal of Network and Systems Management* 2014; **22**(3):434–6.
44. Natarajan S, Ramaiah A, Mathen M. A Software Defined Cloud-Gateway Automation System using OpenFlow. *IEEE 2nd International Conference on Cloud Networking (CloudNet)* 2013:219–26.
45. Kirkpatrick K. Software-defined networking. *Commun. ACM* 2013; **56**(9):16.
46. Zinner T, Jarschel M, Blenk A, Wamser F, Kellerer W. Dynamic Application-Aware Resource Management using Software-Defined Networking: Implementation Prospects and Challenges. *IEEE Network Operations and Management Symposium (NOMS)* 2014:1–6.
47. Kannan K, Banerjee S. Scissors: Dealing with header redundancies in data centers through SDN. In: *8th International Conference on Network and Service Management (CNSM 2012)*: IEEE; 2012, p. 295–301.
48. Dely P, Kassler A, Chow L, Bambos N, Bayer N, Einsiedler H, Peylo C, Mellado D, Sanchez M. A software-defined networking approach for handover management with real-time video in WLANs. *J. Mod. Transport.* 2013; **21**(1):58–65.
49. Vissicchio S, Vanbever L, Bonaventure O. Opportunities and Research Challenges of Hybrid Software Defined Networks. *SIGCOMM Comput. Commun. Rev.* 2014; **44**(2):70–5.
50. Xu X, Zhang H, Dai X, Hou Y, Tao X, Zhang P. SDN Based Next Generation Mobile Network With Service Slicing and Trials. *Communications, China* 2014; **11**(2):65–77.
51. Lara A, Kolasani A, Ramamurthy B. Simplifying network management using Software Defined Networking and OpenFlow. *IEEE International Conference on Advanced Networks and Telecommunciations Systems (ANTS)* 2012:24–9.
52. Manzalini A, Minerva R, Callegati F, Cerroni W, Campi A. Clouds of Virtual Machines in Edge Networks. *IEEE Communications Magazine* 2013:63–70.
53. Hampel G, Steiner M, Bu T. Applying Software-Defined Networking to the Telecom Domain. *16th IEEE Global Internet Symposium* 2013:3339–44.
54. Naudts B, Kind M, Westphal F, Verbrugge S, Colle D, Pickavet M. Techno-economic Analysis of Software Defined Networking as Architecture for the Virtualization of a Mobile Network. In: *European Workshop on Software Defined Networking (EWSDN)*; 2012, p. 67–72.
55. Lombardo A, Manzalini AG, Riccobene V, Schembra G. An Analytical Tool for Performance Evaluation of Software Defined Networking Services. *IEEE Network Operations and Management Symposium (NOMS)* 2014.