Rev. Innova Educ. (2021). Vol 3 No 2 pp. 85-96

Revista Innova Educación

www.revistainnovaeducacion.com

ISSN: 2664-1496 ISSN-L: 2664-1488

Edited by: Instituto Universitario de Innovación Ciencia y Tecnología Inudi Perú

ESSAY

Software-defined network technology for learning in research and education groups

Tecnología de red definida por software para el aprendizaje en grupos de investigación y educación

Tecnologia de rede definida por software para aprendizagem em grupos de pesquisa e educação

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DOI (Genérico) : https://doi.org/10.35622/j.rie.2021.03.005
DOI (Documento en español) : https://doi.org/10.35622/j.rie.2021.03.005.es
DOI (Document in English) : https://doi.org/10.35622/j.rie.2021.03.005.en

Received 06/04/2021/ Acepted 05/07/2021 Published 15/07/2021

ESSAY

KEYWORDS

Hands-on learning, software-defined networking, virtualization, research groups.

ABSTRACT. Software-defined networking (SDN) is an emerging, programmable network paradigm that changes the way networks are designed and managed by introducing an abstraction that decouples control from the data plane. This technology has generated a great deal of interest in both industry and academia. SDN aims to simplify network management while allowing students, faculty, and researchers to experiment with protocols on networks that are used daily. In addition, it has led to the emergence of new trends in education systems, especially the university sector, in computer systems and network administration. Due to the low diffusion of the SDN and the high projection that this technology currently has, the university educational entities must be the ones that venture into this subject. That is why this essay is a synthesis that addresses the importance of applying SDN for educational purposes and in the context of academic research groups.

PALABRAS CLAVE

Aprendizaje práctico, redes definidas por software, virtualización, grupos de investigación.

RESUMEN. La red definida por software (SDN) es un paradigma de red emergente y programable que cambia la forma en que se diseñan y administran las redes al introducir una abstracción que desacopla el control del plano de datos. Esta tecnología ha generado un gran interés tanto en la industria como en la academia. SDN tiene como objetivo simplificar la gestión de la red al tiempo que permite a los estudiantes, docentes e investigadores experimentar con protocolos en las redes que se usan a diario. Además, ha llevado al surgimiento de nuevas tendencias en los sistemas educativos, especialmente el sector universitario, en administración de sistemas y redes computacionales. Debido a la poca difusión de las SDN y la alta proyección que tiene actualmente esta tecnología, es fundamental que sean las entidades educativas universitarias las que incursionen en esta temática. Es por ello que, el presente ensayo es una síntesis donde se aborda la importancia de aplicar las SDN para fines educativos y en el contexto de grupos de investigación académica.

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PALAVRAS-CHAVE

Aprendizagem prática, rede definida por software, virtualização, grupos de pesquisa.

RESUMO. Rede definida por software (SDN) é um paradigma de rede programável emergente que muda a maneira como as redes são projetadas e gerenciadas, introduzindo uma abstração que desacopla o controle do plano de dados. Essa tecnologia gerou um grande interesse na indústria e na academia. SDN visa simplificar o gerenciamento de rede, permitindo que alunos, professores e pesquisadores experimentem protocolos em redes que são usados diariamente. Além disso, tem levado ao surgimento de novas tendências nos sistemas educacionais, especialmente no setor universitário, em sistemas de informática e administração de redes. Devido à baixa difusão do SDN e à alta projeção que esta tecnologia possui atualmente, é fundamental que as entidades de ensino universitário sejam as que se aventurem neste assunto. Por isso, este ensaio é uma síntese que aborda a importância da aplicação do SDN para fins educacionais e no contexto de grupos de pesquisa acadêmica.

1. INTRODUCTION

Universities are high-expectation users and creative innovators when it comes to networking technology. Today, research and education groups connect professors, researchers and students from around the world for projects that require extensive collaboration and transfers of huge volumes of data (Alcaraz et al., 2018).

Behind this scenario, university professors and Computer Technology staff, who specialize in networks, continuously explore how to advance in the field with new designs and/or technological tools. However, meeting the diverse and growing needs of these academic users is a challenge for the university sector. With their fixed design and configuration, traditional networks simply cannot support the dynamic and unpredictable flexibility required for emerging types of applications, advanced levels of collaboration, and increasing data flow speeds (Yalcin et al., 2015; Vega et al., 2019).

To solve this challenge, the networking industry is focusing on a new concept: software-defined networking (SDN). SDN technology is being widely adopted in the domains of commercial networks, government and especially in the academic sector (Niola, 2015; Raychev et al., 2018). However, teaching sdn-related concepts is a challenge due to the inherent nature of this paradigm, its detailed technological tools/skill sets, and the continuous evolution of the information and communication technology (ICT) sector. As a result, there is a growing need to support new initiatives to develop applied research and hands-on training methodologies.

However, the models of traditional networks, on which all the services they offer have been developed and, in addition, where the new digital services are based, considers the network as a set of independent elements, related to each other and that transfer data between them (Spain, 2016). The difficulty is generated when trying to establish the network, and you have to understand that they are individual elements, with connections and different characteristics.

This is where the SDN architecture comes into play, which offers possibilities to interact directly with the network as if it were a whole, then having the following characteristics: 1) flexibility: since the data flow is dynamically adjusted to the changes of the network. 2) Programmable: because it is possible to establish flow rules through programming, 3) manageable: since you have control of the centralized network, and 4) cost-effective: since you do not need to be tied to proprietary software (Bone et al., 2021).

However, the education sector, including academic research, has been working for some time on the advancement of software-based networks. Some examples that can be mentioned are Universidad Central del Ecuador (Spain, 2016), Universidad Central "Marta Abreu" de las Villas in Santa Clara-Cuba (Marín, 2016), Escuela Politécnica Nacional in Quito, Ecuador (Morillo, 2014), Universidad Federal de Tecnología in Minna, Nigeria (Bima et al., 2016), and many others that have driven the trend towards SDN.

That is why it can be said that education linked to computer science (through SDN) is a binomial that seeks balance in the process of teaching and learning the skills necessary for the daily use of computer networks, and also supports learning and the connection that can exist in the educational system around the world , taking into account that this technology facilitates the search, organization and presentation of information, also allowing the development of critical, analytical and creative thinking skills among teachers and students, all focused on a virtualization technology.

The purpose of this essay is to present a synthesis that addresses the importance of applying SDN for educational purposes and in the context of academic research groups, to develop learning processes and knowledge transfer. It also allows to highlight the essence and focus of this technology towards distance and semi-face-to-face education or even face-to-face education, in the context of its use, social impact and relevant characteristics in terms of capacity for interconnection between different types of media and permanent and self-sustaining technological innovation. Therefore, the digital orientation of SDN is emphasized as a relatively new concept in the perception of the educational process, where the center is no longer the teacher, but the student himself. That is why, due to the low diffusion of SDN in many countries and the high projection that this technology currently has worldwide, it is essential that it is the academy that ventures into this subject.

From the methodological point of view, this argumentative essay has a documentary approach of critical analysis, with a level of explanatory knowledge, regarding the potentialities of SDN and its applicability in education and academic research. The argumentative essay is chosen since it allows the promotion of thinking skills, is linked to pedagogy and teaching, considerably favoring the cultivation of speech, the development and use of various tools of the writing of academic discourse.

To this end, it is structured in four points, namely: overview of software-defined networks (SDN), advantages of using SDN for higher education, applications of SDN in engineering disciplines, virtualization technology. Applicability of SDN in virtual laboratories, relevant conclusions and future work on the significant role of this network technology in the development of education, to respond adequately to the current educational demand according to high levels of quality, through the correct and responsible planning, organization, direction and control of the processes that are its own , as well as the lack of knowledge that still exists about the value of technologies in both formal and distance education educational processes.

2. DEVELOPMENT

2.1. Overview of Software-Defined Networking (SDN)

The progressive increase of mobile devices, the initiation of applications in real time, the transmission of video, the massification of social networks, the introduction of systematization in the cloud and many other services,

have resulted in the exponential development of traffic circulating on the network. Despite this, the same technologies as fifty years ago are still being used and advances in new forms of communication and information processing are almost non-existent. These are some of the reasons why existing network architectures do not meet the needs of users today. (Garcia et al., 2014; Benavices et al., 2015). This phenomenon is mainly due to the limitations of current networks, among which are: impossibility of scalability, inconsistent policies, dependence on providers and complexity of the network architecture. To solve these limitations, the industry has created a new network architecture, the SDN architecture. SDNs emerge as a relatively new network paradigm. It is a technological tool that is revolutionizing the field of Information and Communication Technologies (ICT) by controlling the devices of the network from an external software, with the help of the OpenFlow protocol established especially for this purpose. SDN is a technological set that provides a broad perspective of research and is expected to be the basis of a new era of communications in the future. SDNs are oriented in the creation of very dynamic virtual networks based on a diversity and complexity of nodes that are added to the network (routers with computing and storage capabilities), devices and elements located at the edge of the network, close to the users. The Open Networking Foundation (ONF) conceptualizes SDNs as follows: "Software-defined networking is defined as a dynamic, manageable, adaptable, cost-efficient network architecture. Which makes it ideal for the high bandwidth demands and dynamic nature of today's applications. This architecture decouples network control and information forwarding functionality allowing network control to be fully programmable by abstracting network applications and services from the underlying network infrastructure" (ONF, 2012).

SDN technology enables applications to use open programming interfaces to control and grant network resources for the various user needs, processes, techniques, and data types of the application. That is, SDNs work primarily by generating virtual networks that are independent of physical networks. This technology makes applications "think" that they have the entire network to themselves, when in fact they are sharing it, resulting in more servers being able to use the network.

Nowadays, most people communicate and share opinions using computer networks established through IP services. That is why, computer network designers are the professionals who have played a leading role in this new form of communication, and with this to meet a growing demand, computer networks are needed that can be scaled, converged, and managed. Therefore, the technology model attempts to provide new opportunities for students and teachers to receive training using real devices instead of previously used simulations.

In more detail, it aims to provide a simple approach, which relies on virtualization technology to enable the use of real devices for educational purposes, with a system safe and strong enough. In that regard, it is hoped that this model will enable future network and computer system administrators to develop and use a real network and systems management training platform that is much more effective than simulation programs.

This technological set allows both teachers and students to experience motivating educational processes, thanks to a simple and flexible economic development platform, which covers the advantages of both virtualization technology and physical hardware.

2.2. Advantages of using SDN in higher education

Although SDNs offer value for any company, Cosgrove (2011) and Cosgrove (2016) point out various advantages of use that make this technology particularly attractive to higher education institutions that have not yet installed it in their spaces.

Dedicated network resources for research and collaboration. For most institutions, the first application for SDNs is to generate a "Science DMZ", which is nothing more than a piece of network with a high level of data capacity and configuration flexibility. The "Science DMZ" concept was proposed by Engineers at ESnet, a scientific research network managed by the U.S. Department of Energy. This addresses the most common network performance drawbacks found in research institutions by creating an environment that adapts to the needs of high-performance scientific applications, including remote control of experiments and data visualization. "Science DMZ" is scalable, deployable, and simply adaptable to add emerging technologies such as 100 Gigabit Ethernet services, virtual circuits, and software-defined networking capabilities.

Large data transfers. As mentioned above, large and progressive amounts of data are often transferred for different academic research projects. However, the network implications are not simply about having the bandwidth to transport that data from point A to point B in a reasonable period. In a sense of reality, users need better ways to access only the data they need, and they also need to get that data in a way that is ready to be analyzed and processed by their research tools. These capabilities are possible only with the application of SDNs.

Delivery of cloud services. Applications running on a network cloud are becoming more popular to reduce information technology costs and demands, as well as to quickly access new features. Although "cloud" often means the Internet, many of these applications can be easily hosted and delivered on a campus network with SDN.

Data centers and HPC (High Performance Computing) environments. As more data, collaboration, and cloud services are transferred from the university campus network, parallel demands are generated for resources in the institution's data and in high-performance computing spaces. For the institution's own benefit, SDN supports the flexible network connectivity needed to keep information technologies up to date with the growing demand for computing and storage resources.

Network research and technological development. Academic and research institutions have long been leaders in the development of computer technology and networks. Engineering and computer science faculty and students can use SDN to develop solutions to real network problems in a technology lab to access the production network. That is, SDN currently represents a solution, since it can be taken to the laboratory by designing or simulating networks through simulation tools such as mininet. In addition, with SDN technology, networking remains a true academic discipline because it can involve concepts and solution design, as well as work with professional networking staff and test and implement new capabilities developed by students and faculty. Individually or in combination, these use cases are already being explored by higher education's it technology departments.

Some important universities, such as Stanford and Berkeley, are at the forefront of the development of this technology making use of different simulators and /or emulators either for educational or research purposes (Jiménez, 2018). The mininet emulation tool offers free SDN software and documentation on how to install and

use it through SDX Central, in addition to other advantages, so it has become one of the main options for SDN emulation.

However, in the part of university research, the generation of communication networks based on SDN, favors that academic researchers can not only communicate and collaborate with other researchers from other countries, but also, they can manage tools and research resources such as: laboratories, telescopes and electronic repositories, databases, high-performance computer centers , among others, with the consequent improvement of the quality and relevance of its advanced research (Bernal and Mejía, 2016; Jimenez, 2018). What this technology proposes is an approach so that academic researchers can experiment with protocols in the networks that are used daily. Allowing them to experiment with switches uniformly at line speed and with a very high port density. This will allow researchers to evaluate their ideas in a real working environment and be a very useful component for developing large-scale testing platforms.

These are some of the world's universities that include SDN research and teaching in their programs: Ciudad Universitaria de Nueva York, Universidad de Colorado, Stanford University, Princeton University, Universidad Tecnológica Nacional de Argentina, Universidad Católica de Pereira and Universidad Pontificia Bolivariana in Colombia. All of these universities use mininet as an emulation tool for sdn teaching and most have implemented laboratories with equipment that supports OpenFlow for real practice and research (Šuh et al., 2017).

2.3. Applications of SDN in engineering disciplines

In the fields of engineering related to industrial sciences, telecommunications or computer science, it is difficult to manage the teaching and learning of building complex networked systems. However, the SDN paradigm complements many of these needs, providing a tool in which students can have direct contact with large simulated communication infrastructures, apply networking and engineering concepts, and incorporate various types of protocols.

Vega et al. (2019) developed a research entitled "A novel framework for teaching and research: a case study of a Chilean university". It presents an educational framework that integrates key actors, stakeholders, phases and components associated with the teaching-learning process and their corresponding relationships with the use of mininet and the Openflow protocol to represent SDN topologies, this in order to observe how students adapt by themselves to the conditions of the environment and thus configure complex environments at low cost and effort. That study demonstrated that the application of the framework for sdn-related teaching and research activities is beneficial in helping engineering students develop and expand skill sets in programming, networking, and statistical analysis.

Yalcin et al. (2015) developed a model of educational material that was used in courses oriented to the management of computer systems and networks taught in the computer engineering programs of Gazi University (Ankara, Turkey) and Usak University (Usak, Turkey), over a period, all based on SDN technology. In this sense, a total of 137 students found an opportunity to learn the fundamentals of SDN, systems management and other advanced subjects related to computer networks. At this point, the opinions and suggestions of the students on this technological model served as a basis to have a better idea about the effectiveness of this technological tool in educational spaces, especially in the engineering disciplines.

Based on this previous work, it can then be argued that sdn-based information technologies provide many opportunities for the development of educational materials. These opportunities include web-based education, rich content development platforms and simulation programs. These applications are now successfully used in many fields of education. Likewise, the feedback obtained from engineering students shows that the model of development of educational material has shown a good performance within the educational processes and received positive points from the target audience.

Similarly, Dobrilovic et al. (2012) and Yalcin et al. (2015) mention that the SDN technology model, using virtualization technology, provides opportunities to use multiple operating systems in a single physical environment. Thus, a cheaper, more practical, and easier to manage platform model is offered. The use of simulators in educational studies allows you to test applications without damaging the existing physical environment. Students can set up their own virtual machines and access different computer networks without risking damaging existing systems.

In addition, the use of real network devices, in the aforementioned technological model, provides academic researchers with a testing environment for many future scientific studies. In this sense, Nachikethas and Bhaskar (2014) mention that, thanks to SDN, many applications can be developed for basic computer networking, switching and routing training. Similarly, many topology practices can be tested in terms of advanced security issues based on the characteristics of the devices used in the model. In other words, SDNs provide the tools to develop models of educational material for computer systems and networks management that can meet the demands and needs of educational institutions in terms of network education, systems management and security.

Many of the university campuses, at an international level, are not only great users and beneficiaries of this type of technology, but also, they are creators and innovators of new methods, styles, and technological sets, which lead them to become spearheads for the adoption and use of these, with the consequent advantage of acquiring more innovative knowledge, practices and experiences that can be transmitted to the rest of society (Fraire and Duran, 2021). That is why it is important to start educating students and teachers so that they can build, manage, maintain and control such networks.

2.4. Virtualization technology. Applicability of SDN in virtual laboratories

It is well known that the cost of properly equipping a laboratory with the required equipment is relatively high. This has made teaching practice-oriented courses very challenging in educational institutions, especially in those countries that do not have sufficient funding for it. In this sense, laboratory devices must be purchased and configured for use in the laboratory, apart from the linear increase in prices as the number of students increases. Also, there is the problem of the physical space where the material will be placed; likewise, students must be physically present in the laboratory to use the equipment. Therefore, with the use of virtualization these overheads can be eliminated or reduced using software-defined networking, as they promise greater flexibility to create workshops.

However, various research and work has been carried out in relation to the development of virtual laboratories for educational purposes (Ma and Nickerson, 2006; Chan and Martin, 2012; Bima et al., 2016). From these works, virtual laboratories can be classified into two: centralized structured virtual laboratories and decentralized.

In the case of the centralized structure, the nodes have a central server where all remote connections are made to access the laboratory. In this regard, Dobrilovic et al. (2013), at the Federal University of Technology in Minna-Nigeria, developed a centralized virtual laboratory known as VNLab to perform an assessment based on virtualization technologies. In this virtual space, students could access the central server by establishing a remote connection. The results showed that the virtual laboratory has the potential to improve learning in practice-oriented courses due to the ease of conducting practical sessions and, therefore, the elimination and reduction of costs in the acquisition of laboratory equipment.

Whereas, in the decentralized structure, nodes operate without dependence on a central server. That is, this creates a wide range of advantages for the development of the virtual laboratory. The use of a decentralized structure is a trend between education and professional fields (Cano et al., 2016). These same authors developed a virtual laboratory based on cybersecurity with the game-based learning technique (GBL) used to encourage learning among students. Obviously, this is due to the great advantages derived from its use, which include reuse and the flexibility to make changes. González et al. (2011) used some free virtualization tools to develop a virtual lab for educational purposes. The application of ideas developed based on the advancement of SDN technology in educational environments makes valuable contributions to the processes of teaching and learning.

Likewise, using the mininet SDN network emulation tool, scenarios can be developed to share knowledge on how to manage science laboratories virtually and effectively and thus benefit the learning needs of students. A virtual lab is an interactive environment for creating and performing simulated experiments. It involves conducting experiments with domain-dependent simulation programs. In fact, a virtual reality technology can be adapted to create a virtual lab to simulate processes and actions in physical labs.

These virtual labs, using SDN technology, offer users, especially teachers and students, learning experiences that may be ineffective in physical classrooms. Users can design, develop, and achieve predetermined experiments that simulate experiences and processes in real-world contexts. All students can get involved and participate, unlike physical systems where only a few students can do the same and learn. Virtual labs can be used with display technology as interactive projectors or smart planboards for an all-inclusive class. They can complement existing ones or be used as freelancers, especially for courses where physical laboratories cannot be developed due to lack of resources and real practices. That is why, virtual laboratories are even more appropriate, important and cost-effective for educational institutions in developing countries where physical facilities are poorly equipped or do not exist (Ayega and Khan, 2020; Polanco and Guerrero, 2020; Fraire and Duran, 2021).

Based on the above, the applicability in various environments of the SDN guidelines can focus on multidisciplinary sciences that include Biology, Chemistry, Physics and topics related to Electrical Engineering, Mechanics, Computer Science and Chemistry, Biotechnology, Biomedical and Civil Engineering, Earth Sciences and Agricultural Sciences. In addition, when using this technological package can be used, for example, sensor networks that control pH, temperature, humidity, or any other variable of interest; this will allow researchers to access much of the information they want in wider areas. Similarly, it allows communities of professionals to create and share resources that would otherwise be costly and unavailable in conventional systems and practices, thereby complementing learning, teaching and research.

Therefore, these simulators are a great opportunity for the education sector. Here, both the student and the teacher can ask themselves, experiment, manipulate variables of a predetermined situation by the program, contrast results and ask themselves again. In turn, several studies indicate that virtual laboratories promote the motivation, participation, and commitment of students by positively impacting their learning (Ayega and Khan, 2020; Bone et al., 2021).

The design and implementation of a fully operational SDN network is illustrated in a practical way using a virtualization environment, which aims to learn the basics of managing SDN routing. In addition, dynamic evaluation and feedback mechanisms may be integrated into these emulations that allow students to map experiments to test, confirm, and/or test their understanding.

Fuertes et al (2009) conducted several studies on the use of virtualization technologies in universities in Spain and Ecuador. The results of these studies showed that the virtualization platform brings various advantages in these environments, such as: software testing and confirmation, low cost, teaching-learning platform, network services and traffic analysis testing.

In a report published by IBM, they stated that most US educational institutions stated that the regular purchase of new computers for students would place a burden on the country's economy. That is why they suggested that virtualization technology allows the use of available equipment for longer (IBM, 2006). In other words, virtualization technology, focused on SDN, is a model for the development of educational material for the management of computer systems and networks that can meet the demands and needs of educational institutions in terms of network education, systems management and security.

In this context, the use of virtual computing platforms offers certain advantages: First, as an important option to provide economic platforms for research and experimentation. Second, as a competitive strategy to share hardware and reduce hardware investment. Thirdly, as an educational innovation to provide cost-effective platforms for teaching-learning processes. In addition, this technology reduces the risk of damage in real environments, as well as the cost of development and experimentation.

3. CONCLUSIONS AND FUTURE WORK

The main conclusions of this trial focus on the beneficial characteristics of SDN compared to other existing technologies, and on the potential capabilities to build practical scenarios with a low cost of infrastructure, configuration time and effort, in addition to favoring students and research teachers to concentrate their time, in addition to learning the essential objectives of the subject, by properly exploiting its competences.

Traditional data networks have definitely reached the limit of their capabilities. This is an ideal time for institutions of higher education to begin defining strategies for bringing SDN technology to their campuses. Ideally, these strategies will cover network plan updates and budgets, as well as pilot projects to gain experience with this new networking approach.

Developments in recent years in the field of ICT are creating a greater demand for bandwidth and Internet access by users, as well as a more flexible and dynamic management of their services. The use of SDN architecture

provides significant advantages over traditional networks such as: ease of innovation and management, supplier independence and increased performance. SDN is seen as a promising solution to meet these demands.

SDN technology provides a platform for the creation of educational materials on topics related to the management of networks and computer systems. At this point, the materials created meet the needs related to teaching and learning within computer network, systems management, and training processes in network security carried out in educational institutions. In this sense, it would be interesting to develop future studies that address the compatibility of this model with cloud computing technology so that it is possible to integrate this tool into a model of management of networks and computer systems that can be accessed remotely. If this technology is implemented and simulators are used, it can allow or facilitate researchers, students, and others to implement complex systems.

Finally, it is recommended to extend the development of other projects related to SDN that can be made available to students and that contribute to improving their skills in the subjects they exercise the profession. Make available to users in general interested in these complementary materials may be available on interactive e-learning platforms and can be accessed by the network.

Conflicto de intereses / Competing interests:

El autor declara que no incurre en conflictos de intereses.

Rol de los autores / Authors Roles:

No aplica.

Fuentes de financiamiento / Funding:

El autor declara que no recibió un fondo específico para esta investigación.

Aspectos éticos / legales; Ethics / legals:

El autor declara no haber incurrido en aspectos antiéticos, ni haber omitido aspectos legales en la realización de la investigación.

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