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A CURRENT VISION

State of the art in software defined networking (SDN)

Estado del arte en redes definidas por software (SDN)

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ABSTRACT

The growth of networks at a global level is inevitable due to the increase of users, devices and applications, such as: Internet of Things (IoT), processing and analysis of large amounts of information (Big Data), or streaming audio and video, which has demanded from the systems, greater storage resources and bandwidth. To this purpose, diverse paradigms have emerged for the centralized management of all the components of a network through fully administrable, centralized and dynamic technological platforms; among these is SDN (Software-Defined Networks). This document, consequently, establishes the state-of-art from a documentary research of a categorical type to be used as a frame of reference for research in the area of SDN by the Research Group of New Technologies of Social Application GIDENUTAS ascribed to the University Francisco Jose de Caldas. This is chronologically limited to a review, from 2007 until today, focused on the countries that have promoted the development and implementation of this new paradigm, using databases such as IEEE Xplore, Google Scholar, as well as documents from standardization organizations such as ONF and ITU.

RESUMEN

El crecimiento de las redes a nivel global es inevitable debido al aumento de usuarios, dispositivos y aplicaciones derivados de conceptos como pueden ser el Internet de las cosas (IoT, de inglés Internet-of-Things), el procesamiento y análisis de grandes cantidades de información (Big Data), o la transmisión de audio y video en vivo (Streaming), lo cual ha demandado de los sistemas mayores recursos de almacenamiento, ancho de banda y alta flexibilidad, entre otras características. Por lo anterior, han emergido paradigmas para la gestión centralizada de todos los componentes de una red mediante plataformas tecnológicas totalmente administrables, centralizadas y dinámicas; entre estas se encuentran SD-WAN (Software Defined-Wide Área Network) o SDR (Software-Defined Radio), ambas surgidas gracias al concepto de las Redes Definidas por Software o SDN (del inglés Software-Defined Networking). El presente documento, en consecuencia, establece un estado de arte a partir de una investigación documental de tipo categorial para utilizarse como un marco de referencia de investigaciones en el área de SDN por el grupo de Investigación de Nuevas Tecnologías de Aplicación Social GIDENUTAS adscrito a la Universidad Distrital Francisco José de Caldas. Esta se limita cronológicamente a una revisión, desde el año 2007 hasta hoy, enfocada en los países que han promovido el desarrollo e implementación de este nuevo paradigma, recurriendo a bases de datos como IEEE Xplore, Google Scholar, así como documentos de organizaciones de estandarización como la ONF y la ITU.

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1. Introduction

Since the birth of the Internet in 1969, from the ARPANET military project, historically the growth of this network has been sustained and continuous, so that it had about 4 billion connections by 2017 [1]. It is not a secret that, for professionals who manage the network infrastructure in different companies and organizations, it is a challenge to maintain an optimal functioning in all its infrastructure when it is growing and is faced with problems such as the increase of devices, interoperability, among others.

On the other hand, there has also been a need to keep the infrastructure safe where key and strategic information is stored for companies and organizations, particularly in business models with sophisticated databases of customers and suppliers. In this sense, there has been the creation of paradigms such as Cloud Computing, which have allowed this information to be stored and stored remotely, with high availability, confidentiality and authenticity, and taking full advantage of the resources of the infrastructure.

However, in the last few years, alternatives have emerged such as the Ethane project, developed at Stanford University in 2006–led by Nick McKeown– which consisted of a controller with 12 switches that managed the traffic of 300 hosts, project in which one of the developers of OpenFlow protocol (and therefore SDN), Martin Casado, participated as a Doctorate student [2]. Later, Casado together with McKeown and Scott Schenker created in 2007 [3] the pioneer company in SDN: Nicira Inc. to solve the aforementioned challenges illustrated in the network virtualization research conducted by Casado, [4].

The first version of OpenFlow is officially published as a "test" protocol in 2008, following the functional virtualization philosophy (NFV) [5]. In 2011, Nicira launched a network virtualization platform (NPV), a network controller that works together with virtualization tools for cloud computing, storage and image management. Nicira Inc. was purchased in 2011 by VMware for USD 1,260 million [6], to implement network virtualization solutions in corporate environments, improving its service portfolio, [7]. From that time to today, it is interesting that the literature review of the subject evidences that only 8 sources out of the 64 referenced are of Spanish-speaking origin, and of these only 2 are Colombian, so the present investigation is justified documentary to demarcate a baseline for future research in the area of SDN.

The document is structured as follows: Initially, the methodology of documentary research is established; Subsequently, the results of this are mentioned, where topics such as components of the SDN architecture, its main applications and controllers are described; then, it is generalized about network virtualization, and SDN Standardization Organizations; and finally the conclusions are established.

2. Methodology

To establish the categories and subcategories developed in the present review, it was selected the index method [8]. This method consists in developing, in the first place, a global or general SDN index, and refining it until it is sufficiently specific in the different categories or subcategories of the study. In the previous methodological sense, it is found that in the last decade, the development of SDN research has increased in which study categories such as: Architecture, Controllers, NFV, Applications, and Regulations have excelled.

From the exposed perspective, SDN Architecture has consolidated subcategories object of study such as: control plane, data plane, and application plane. In Drivers, subcategories on open source devices– such as ONOS and ODL -, and proprietary source– such as VMware NSX and Huawei Agile -. Regarding NFV, the associated components stand out as subcategories, as well as the relationship of NFV with SDN. In terms of applications related to SDN, subcategories have been focused on developments such as: IoT, Datacenter, 5G, and Big data. And in terms of Regulations, sectoral regulatory subcategories have been established: ONF, IRTF and ITU.

As a result, a review article is structured based on the search of sources from the IEEE Xplore, Google Scholar databases, as well as documentation from ONF and ITU; with keyword search such as SDN Architecture, SDN Drivers, NFV for SDN, SDN Applications, and Regulations for SDN.

For the analysis of the documents of this research, of an exploratory and documentary nature, sources were assumed in each of the categories and subcategories, circumscribing the European continent and North America, and temporarily limited to the last decade, since it is in space and time where the largest research and applications based on SDN have been developed. As a consequence, a context for this network paradigm will be provided, focused on current technological trends and their perspective. The categorization is observed in Figures 1 and 2.

Figure 1. Research model for the state of developed art.

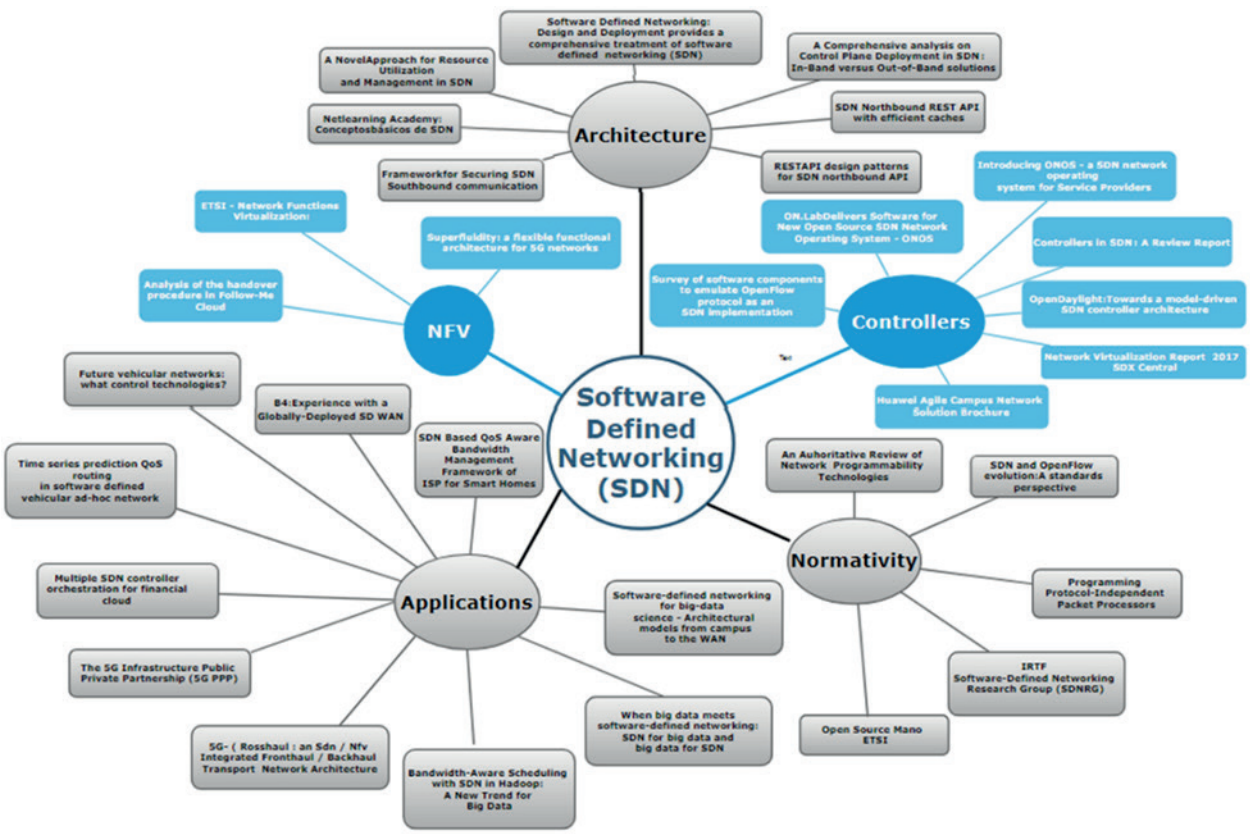

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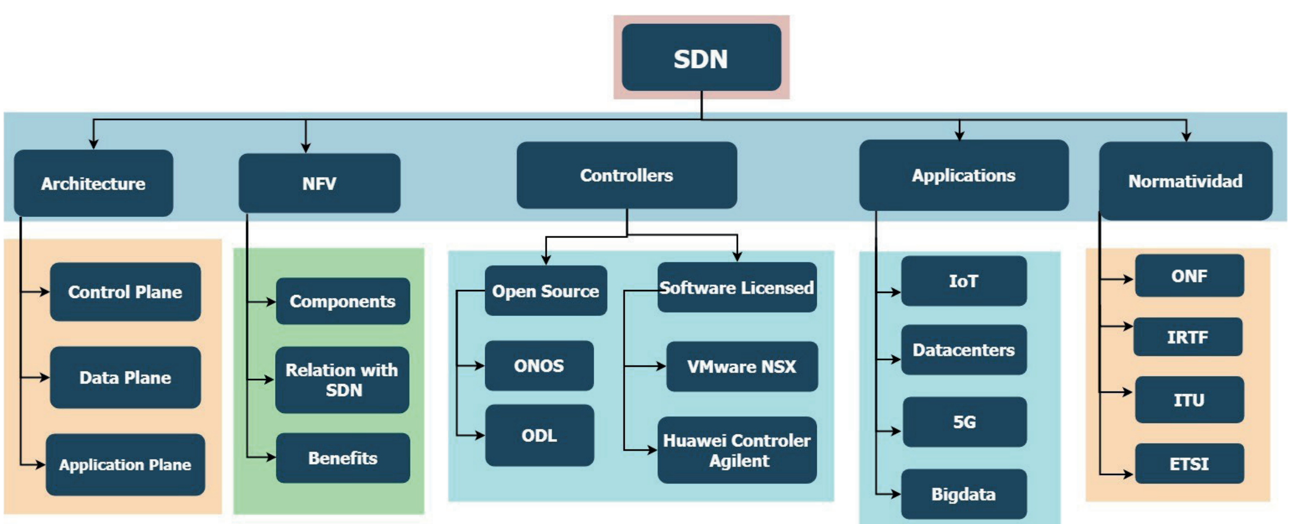
Figure 2. Subcategorization of the research model for the developed state of art.



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3. SDN architecture

The concept of software defined networks (SDN) is based on a model composed of three layers: application plane, control plane and data plane, which optimally reinvent and automate the network infrastructure. Its architecture aims to disaggregate the control and data planes in network devices such as switches and routers, [9]. The control plane is responsible for making decisions regarding traffic that interacts with any device in the network, while the data plane is the one that executes the tasks of transporting data packets.

In Figure 3 it can be seen that the architecture of software-defined networks is conceptually composed of three layers: infrastructure, control and application [10]. There are also API's that communicate these three layers: Northbound API (Northbound) and Southbound API (Southbound), depending on the communication address with reference to the SDN controller. Within the SDN environment, the development of open source APIs is promoted, which gives this new paradigm more flexibility and dynamism.

3.1. Data Plane

The Data Plane –or also called the infrastructure layer– is made up of all the network devices, among them the switches, routers, and access points responsible for transporting all the information of the users that circulates through a network [11]. These devices do not longer have predefined and fixed functionality, but are characterized by a set of instructions given by the control plane. Thus, the same hardware could work as a router or as a firewall, depending on what the network manager has defined.

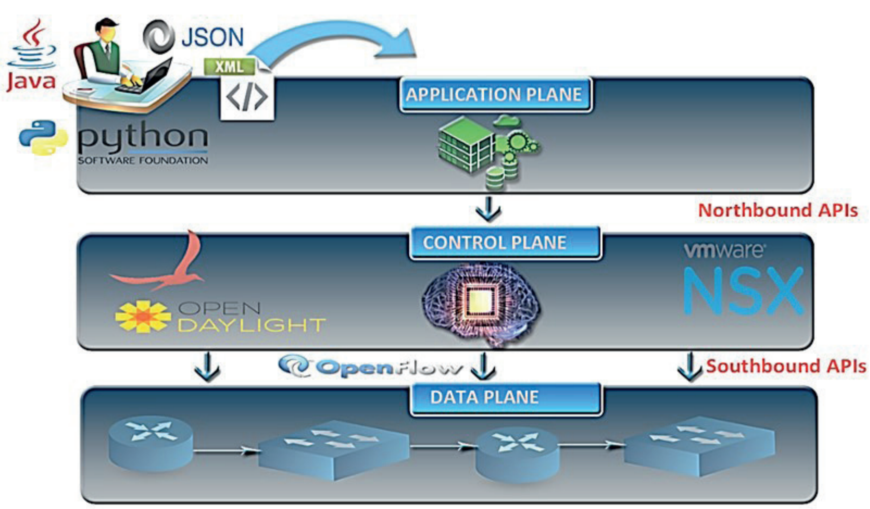
3.2. Control Plane

The Control Plane is responsible for centralizing the control of the entire flow of information that circulates through the Data Plane. This contains the policies of forwarding or diversion of data, flow tables, and has a general perspective of the entire network hosted in an SDN Controller [4]. As it can be seen in Figure 3, there are APIs (Application Programmable Interface) Southbound, such as the OpenFlow protocol, which allow a controller like Opendaylight or NSX to send the set of policies and configurations to all the devices that make up the data plane. These APIs are of crucial importance for the strict separation of the functions of the data and control planes [12], [13]. There are also Northbound APIs such as Restful API [14] or SDMN API [15], which define a central place in the infrastructure to mediate between global application policies and network policies, allowing the application layer to communicate with the control layer [16]

3.3. Application Plane

The last plane or layer, but not least important, is the Application Plane. It is where the development of diverse applications that allow a communication and interaction with all the architecture is done quickly, together with the support of the Northbound APIs that

Figure 3. Elements of the Architecture of the SDN networks.



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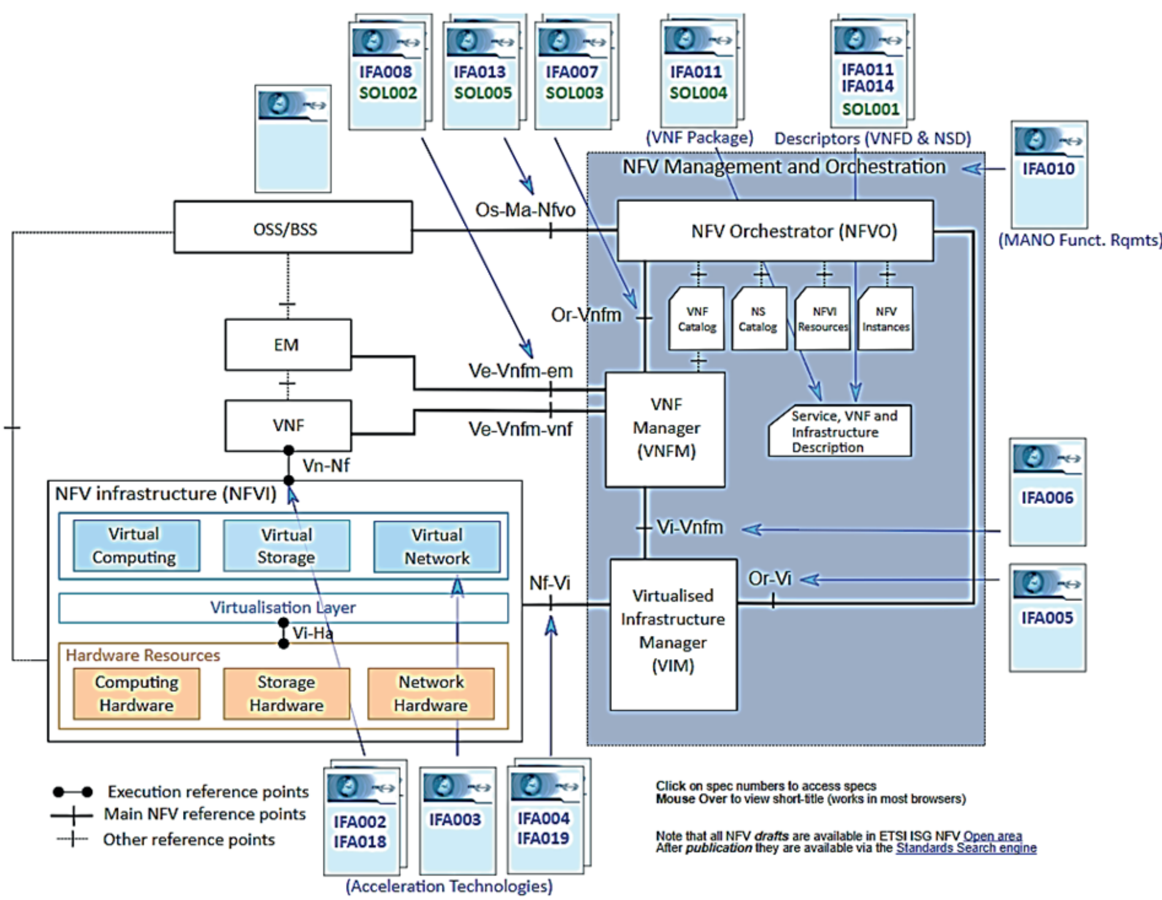
achieve the communication of this layer towards the underlying layers. This part of the architecture has the ability to obtain a more abstract perspective of the network, knowing from the quantity and distribution of the connected devices to the collection of statistics of network behavior, and that is where the decisions about its administration are made. Therefore, it is necessary that the development of these high level applications will be created and implemented by communities that promote development through open source platforms, contributing to standardization [3], and adding features such as secure encryption and portability. In this regard, the development of applications with REST[5] architecture has gained ground in SDN, providing benefits with service-oriented applications regardless of the programming language and executables in various platforms. This application architecture is supported by new languages such as: Javascript, JSON[6] and Python [17], [18], which have enabled the management and administration of networks to be carried on mobile platforms.

4. Virtualization of Network Functions (NFV)

Network Function Virtualization (NFV) is a paradigm that complements the concept of software defined networks (SDN). As its name suggests, NFV aims to virtualize network functions (whether it will be a router, web service or load balancer), so that these do not depend on the hardware in which they are deployed, which is usual in traditional networks. SDN can be used at a low level to connect virtualized infrastructure, or at a high level to help compose virtualized network functions in NFV, for instance.

Figure 4 shows the NFV architecture as defined by ETSI, the entity in charge of its standardization, as well as the associated documents. Broadly speaking, there are three levels: infrastructure (NFVI), network function manager (VNFM) and orchestrator (NFVO).

Figure 4. NFV architecture according to ETSI [19].



5 Representational State Transfer: it is a software architecture style for distributed hypermedia systems such as the World Wide Web
6 JSON: format based on standard text to represent structured data

The difference between NFV and SDN, is that SDN–by definition- separates the control plane and data, generating the opportunity to implement new abstractions and interfaces that facilitate the control of the network, while NFV focuses on replacing hardware network devices by software executed in hosts or servers of general purpose (Commercial off-the-shelf, COTS), so that these later can be lodged in centers of data, as example.

One of the main advantages of NFV is the reduction of the price and availability of the servers, since there is not dependency on a specific service provider or manufacturer, but any service could potentially be deployed on any server. This in turn, generates a second advantage related to the network functionality which can be hosted anywhere based on its effectiveness or low cost. 5G networks support their evolution in NFV due to this advantage: a 5G network service can be hosted in the core or in the edge, even in different parts of the edge depending on the user's location, adapting easily. As an example, the Superfluidity project [20] relies on this advantage. A possible application would be high-speed trains, where coverage is usually lost due to radio station changes, but thanks to the combination of SDN and NFV, the service could be easily resized following the user and transparently to this one., [21].

Finally, another feature of NFV is that the functions can be combined among them, deploy and update automatically, as just another software. This facilitates the evolution and diagnosis of the network.

5. SDN drivers

The SDN controller is the implementation of the central part of the architecture of the software defined networks; that is, it is the control plane in which different applications of the application plane can be instantiated. The SDN controller is responsible for centralizing all the policies and guidelines that are executed from the Northbound APIs [22]. Its main task is the intelligent control of managed resources to deliver a better quality of the services offered in an environment where the demand for resources is variable, achieving an optimization of networks in real time [23]. Next, the most outstanding SDN controllers in the current market and a description of their main characteristics are presented.

5.1. ONOS (Open Network Operating System)

In 2014 the ONOS project joined as a collaborative project in the LINUX Foundation [24], its main objective is to provide network service providers with high availability, scalability and performance, so that end users can obtain a greater service experience [24]. It uses a modularity method that allows adapting to the different environments in which applications can be developed with SDN, in turn, it provides Northbound APIs that simplify the administration and control configuration processes. It has support for protocols such as OpenFlow, Netconf[7], Tl[8]1, SNMP[9], BGP[10] among others. ONOS brings portability and dynamism with REST API[11] systems, extensible user interfaces and CLI on the Web. Its main programming language is JAVA, [25].

It should be noted that the ONOS platform is currently supported by the ONF community, which in turn is responsible for generating the recommendations and standardization documents for the SDN paradigm.

5.2. ODL (OpenDaylight)

This collaborative project–under the leadership of the LINUX foundation–launched in 2013, and created to incentivize SDN and NFV, provides commercial use solutions that address existing network environments. The core of its platform is composed of an abstraction layer of the service that is supported by the MD-SAL model [26].

The ODL project architecture applies the Open Service Gate Initiative (OSGi) specifications, which allows the creation of platforms so that the different services offered with this controller have compatibility [27]. It also supports Southbound protocols such as: BGP, OpenFlow and OVSDB.

ODL is the project that leads the implementation of SDN with free development platforms, which is why many industry members consider it a default standard [28].

7 It is a network administration protocol developed and standardized by IETF
8 Transaction Language 1 Southbound protocol that communicates with the transport layer
9 It is an application layer protocol that facilitates the exchange of management information between network devices.
10 The border gateway protocol is a protocol by which routing information is exchanged between autonomous systems
11 Representational State Transfer. Set of restrictions with which we can create a software architecture style

5.3. VMware NSX

In 2012, a year after the purchase of Nicira by VMware, this company delivered to the market its virtualization platform called NSX with which it aimed to expand the technologies related to network virtualization. NSX decides to take a step forward with virtualization by adopting features such as: load balancing, firewalls in the core of distributed L4.-7 devices [29] including support to hypervisors from other manufacturers, offering dynamism and interoperability of platforms.

The use of NSX is popular in integral solutions for Cloud Computing and SD-WAN, because it allows to optimize public and private cloud operations. It also facilitates the combination of network and security services, benefiting the automation, simplification and distribution of services in data centers [30].

5.4. Huawei Agile Controller

The multinational technology company has developed this controller to cover markets of LAN, WAN, IoT, DCN, Government and financial entities, offering an automatic implementation, intelligent control and bandwidth adjustments on demand, improving the optimization of resources in the cloud and improving the experience of the solution for the end user.

This controller is adaptable to ONOS, ODL eco systems that are developed with open source, within the protocols supported by its SDN platform are the following: OpenFlow, BGP, IGP, OVSDB and CLI. Its main programming codes are written in Python and JAVA [31]. A remarkable feature is that it has an Internet packet preservation algorithm (iPCA), which detects the location of a fault in the quality of service, allowing the administrators to determine if a bad service experience has been caused, [32].

6. Articulated applications with SDN

This category contains a considerable number of investigations of different current technological trends that use SDN technologies.

6.1. IoT

Initially, in [33] an SDN architecture for intelligent homes is proposed, as it can be seen in Figure 5, where the bandwidth allocation of the devices is optimized and internal domestic traffic is controlled. This architecture is composed of SDN Smart Home Cloud, and Massive SDN enable Smart Homes, which are interconnected with the OpenFlow protocol. In the first, the SDN controller communicates with the automatic configuration module (ACM), with the Bandwidth Allocation module (BAM), and domestic device databases (HDD)[12]. The Automatic Configuration Module can be used to help each IoT device record and update device information. The BAM has an allocation algorithm to program bandwidth resources for internal domestic traffic.

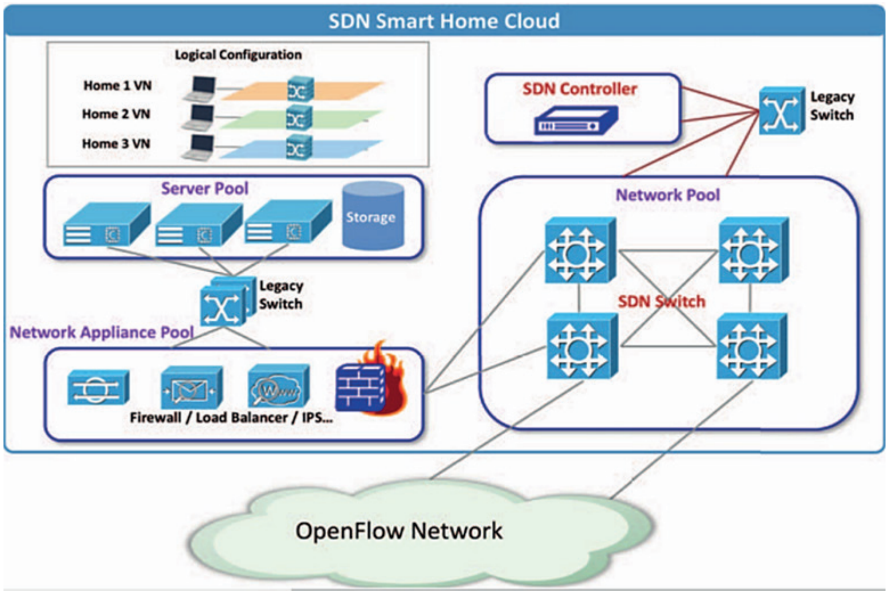
However, the architecture implementation environment was developed in a virtual environment with VMware Center Server 6.0.0, and the Linux operating system Ubuntu 16.04 Kernel version 4.4.0 was implemented in a powerful 48-core server. The Ryu[13] driver was installed to manage the SDN OpenFlow virtual swicthes created by Mininet[14]. The results of the implementation show that the proposed architecture overcomes the traditional ISP[15] bandwidth allocation architecture by increasing the data transfer rate to 30%, reducing 60% delay and 90% instability.

In this same line, Jang et al. [34] propose a bandwidth allocation module, where it must have different bandwidth allocation policies for both internal domestic traffic and external Internet traffic. The bandwidth of the internal network is limited to the bandwidth of the local area network and the bandwidth of the external Internet is limited to the bandwidth subscribed with the ISP. The policy is carried out through the bandwidth allocation module and it is carried out using the Home OpenFlow switch and the ISP SDN switch.

On the other hand, in [35] an integrated solution of wireless power line (PLW) is developed, due to the lack of continuous connectivity when using only wireless in most domestic environments. This approach seeks to respond to the progress of an omnipresent and sustainable infrastructure for new integrated services with IoT and SDN. The reason that supports this research is the idea of having total connectivity within a fast data network in truly intelligent home devices such as: lights, appliances, and power outlets. Since these devices are generally

12 Home device database
13 It is an open network controller (SDN) designed to increase the agility of the network by facilitating the management and adaptation of the way in which traffic is handled.
14 Mininet: Tool that allows you to configure a network emulation environment within a single system.
15 ISP: Internet service provider

Figure 5. Architecture for a Smart Home with SDN [33].



connected to the grid's power supply system, it makes sense to use PLC[16] instead of other network technologies. The interface standard between the systems is IEEE 1905.1[17] IEEE P1905.1. The article suggests the development of devices such as wireless routers embedded with a Power Line Wireless (PLW) system that could control the whole network of the smart home, connecting mobile and static devices, increasing data speeds in parallel.

On the other hand, [36] describes the use of technologies for the administration and support of the requirements of the Internet of Vehicles (IoV) developed with SDN. The article mentions the importance of carrying out management and control with SDN technology of Ad Hoc Vehicular Networks (VANET) to mitigate the number of deaths caused by accidents in road traffic, which reached the Figure of 1.25 Million for 2010 according to the Organization World Health. It is mentioned that SDN provides a dynamic way to configure the devices of each of the wireless nodes in the network (see Figure 6); Additionally, the system responds much faster to changes in the topology of the network; The controller has also the ability to collect traffic statistics that allow decision-making to control the flow of information and other critical aspects of the network. Finally, it is concluded that SDN alone cannot meet the requirements of VANET / IoV[18], it is necessary to complement the solution with technologies such as Fog Computing to mitigate the latency time, an indispensable factor for the safety of automotive applications.

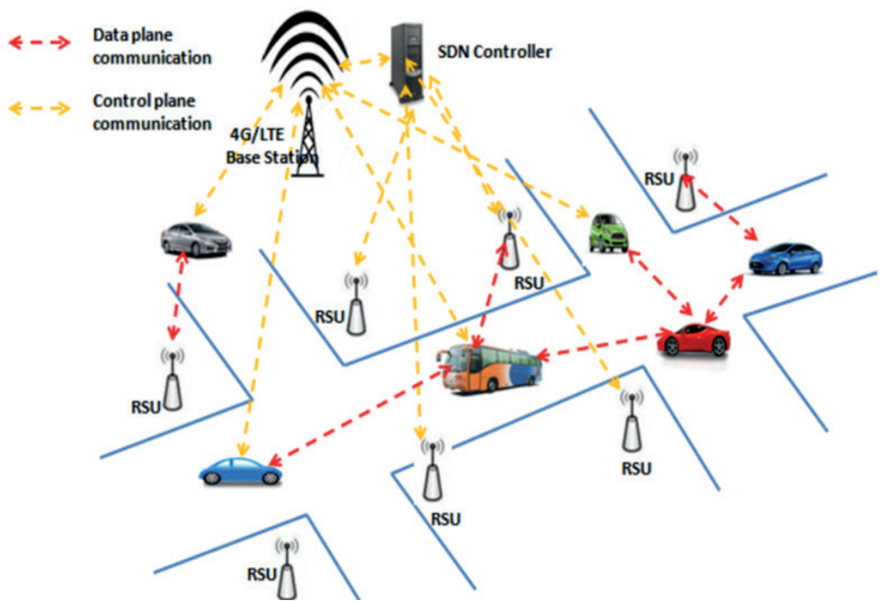
Besides, in [37] we present an architecture with a routing protocol based on prediction techniques that provide better performance and characteristics to VANET SDN, as indicated in Figure 6.

In another sense, [38] shows the development of SDN for WSN[19] (Wireless Sensors Network), with the implementation of new protocols based on the same centralized control logic to dynamically adjust the needs of a wireless sensor system, key elements in the IoT paradigm. The investigation shows the analysis and evaluation of the WSN operation using the CORAL-SDN[20] protocol.

Similarly, in relation to the aforementioned, the energy savings and the mobility of sensor nodes is something inherent in WSN, to which [39] assumes taking a model to compare the power consumption of traditional WSN networks, together with Mininet and the Floodlight controller[21], which allow it to propose a more dynamic architecture and that reduces the energy consumption when processing a package of data in a SDN network since the nodes only transport information.

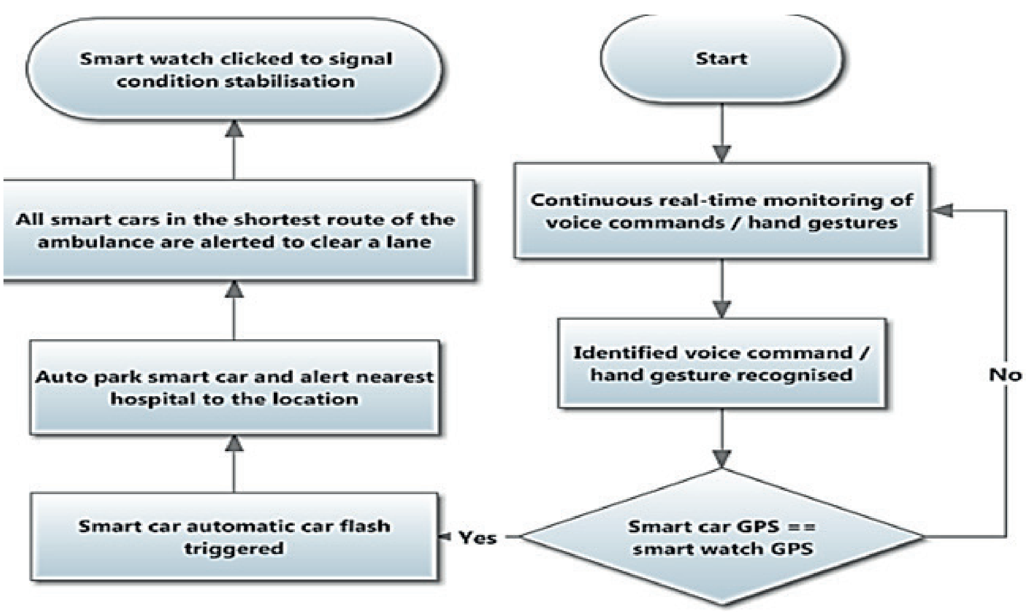
16 Programmable Logic Controller: It is an electronic device that is programmed to perform control actions automatically.
17 IEEE 1905.1: IEEE standard that defines a network enabler for home networks compatible with wireless and wireline technologies.
18 Internet of Vehicles: IoT Research Branch applied to vehicular systems
19 Wireless sensor networks, sensor network and wireless actuators
20 Protocol used to centralize the control of the WSN
21 It is an open SDN controller, business class with apache license and java based.

Figure 6. Communication SDN-VANET, [37].



Finally, in [40] the authors describe a new IoT health service for the detection of a heart attack in real time when driving a vehicle, using two models: voice control and gestures with smart watches. In the first, through the use of voice commands, the emergency mechanism is activated, which includes sending the coordinates of the vehicle to the nearest hospitals and messages to neighboring vehicles to clear a lane. In case the coordinates of the vehicle with the smart watch do not coincide, the system will understand that the voice command is out of context and will reduce the cases of false emergence. In the model of Figure 7, it is possible to see the control of gestures that is carried out with the reading of wrist gestures, heart rate, and in the event of a heart attack outside the vehicle and within a vehicular network smart is notified to the nearest ambulance, vehicles and hospitals, and thus reduce the response time to the emergency presented.

Figure 7. Model of control of voice and gestures, [40].



6.2.Datacenters

One of the most ambitious projects using SDN is the one described in [41]. There is a description of the design, implementation and evaluation of B4, a private WAN that connects Google's data centers around the world. B4 has a series of unique characteristics: i) massive bandwidth requirements deployed in several places globally, ii) elastic demand for traffic that seeks to maximize average bandwidth, and iii) total control over peripheral servers and network, which allows to limit the speed and measure the demand of edge servers.

With respect to the above mentioned, there is a simplified coordination and orchestration for configurations, provisioning or planned and unplanned network updates. SDN allowed homogeneous use of infrastructure resources regardless of the hardware employed.

On the other hand, [42] presents the description of connectivity models between Datacenters (DC), under the operation of an architecture based on ABNO, in view of the inefficient use of resources in a static connectivity. DC operators do not only deal with tasks to optimize energy consumption, they must also provide solutions for the efficient use of resources for the provisioning of services.

Therefore, the so-called network-driven model makes use of an SDN operator where applications request data transfer instead of connectivity with another DC. The originating DC makes the transfer request to the SDN operator, specifying destination, volume of information, and maximum time for the transfer. Then, the SDN operator requests ABNO[22] the channel with the greatest availability of available spectrum width, without neglecting local policies and service level agreements (SLA), finally, the response is sent to the originating DC, making the connection through the respective channel.

In the manner previously described, Cloud service providers can benefit from the interconnection between their DCs, which not only provides load balancing solutions but also increases their revenues from the use of IT resources. Migrating virtual machines (MV), and synchronizing databases according to the available bandwidth in the different connectivity links, the use of the network-driven model decreases the transfer time by around 60% compared to static connectivity.

Likewise, in [43] the benefits that operators provide to users of computing resources and storage distributed in micro data centers are mentioned, in the same way that network operators optimize the use of dispersed physical network resources like a single virtual resource, reducing administration costs.

In contrast, [44] proposes a solution to the problem of orchestrating multiple SDN controllers in a regional financial Cloud infrastructure, using OpenStack 'Region', concluding that the proposed model is adjusted only when there are few modifications in the implementation of OpenStack what is relevant in this research is the work with interregional networks.

Furthermore, an important factor in SDN networks is security. This is how [45] describes that in DC networks supported by SDN controllers, when mitigating and reacting to any type of cyber-attack, response times are slow because security management is in charge of human operators. Therefore, a virtualization of the network functions with FPGA[23] is provided (see Figure 8) that substantially improves the switching rates, improving the accuracy and speed in the detection of security problems and other traffic anomalies to the SDN controller.

Besides, the diffusion of cloud-based services using virtualization technologies has significantly increased the complexity of data center management, which has led to the planning of new solutions to performance problems for the intra-network. DC. That is why in [46] it is possible to see the implementation of algorithms for the management of virtual machines (MV)[24] to improve features such as scalability, network stability, and growth of hosts. Finally, it is proposed to add other features such as MV migration and storage.

In [47], Majdoub et al. propose a scheme that improves the efficiency of bandwidth overload used in communication between switches, for this, the network is divided into several sections. These are only required from a single MPLS[25] tag; then, specific exchange nodes are selected within each section.

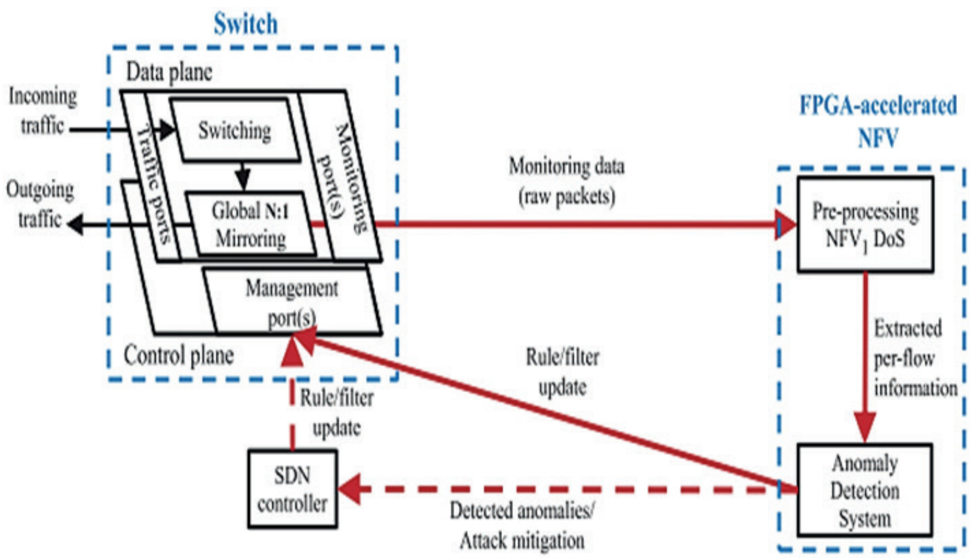
22 Application based network operations: Modular architecture that provides advanced network functionalities, such as virtualization of network services, coordination and optimization between applications and network resources.

23 Field Programmable Gate Array, are devices that allow us to describe a digital circuit using a specific language (VHDL and Verilog).

24 software that simulates a computer system and can run programs as if it were a real computer.

25 Multiprotocol label switching, designed to unify the data transport service for circuit-based and packet-based networks

Figure 8. Real-time network security design based on FPGA, [45].



The exchange node functions as an intermediate node that divides the entire route into sub-routes and limits the number of labels to be used. However, this selection of nodes relies on a large extent on the network topology.

6.3.5G

In [48], Elgendi et al. transfer the concept of SDN to the control and management of cellular and wireless network infrastructure, making it easier for a BS[26] (Base Station) to perform packet transport functions under the command of applications that are executed from a logically centralized controller. It is also argued that, due to the growing demand for greater capacity and coverage by mobile network users, a DenseNets architecture is proposed that increases the number of femto-cells in places where the number of subscribers is high, enabling significant interoperability with heterogeneous devices, thus achieving convergence to networks such as 5G.

In [49] Demestichas, Panagiotis et al. point out how wireless operators are trying to meet the growing demand for traffic [50] by deploying cells of various sizes (mostly small cells), as shown in Figure 9, instead of using only basic macrobase stations (BS). In particular, the introduction of heterogeneity and the cloud access network (RAN) is investigated, through the development of intelligent technologies based on recent concepts such as SDN and NFV.

Moreover, [51] describes the 5G-Crosshaul project, which aims to integrate interfaces and technologies of fronthaul and backhaul, applying the management and orchestration principles of SDN (OpenDaylight and ONOS) and NFV (ETSI). In [52], the same authors, in a previous work, justify unified backhaul and fronthaul as a precursor that has the most stringent requirements not only in terms of data speed but also in latency, jitter and bit error rate and that It is also in line with the research activities carried out in the Next Generation Fronthaul Interface Alliance (NGFI), IEEE 1914, and IEEE 802.1, where a packaged version of fronthaul traffic is provided, compatible with existing backhaul implementations.

In contrast to the above, in [53] an E2E Cloud-Native network architecture is mentioned that provides companies and people with a unique real-time experience with diversified KPI[27] services, and willing to co-exist multiple standards (5G, LTE And Wi-Fi), incorporating multiple connectivity technologies and the new 5G air interface. The 5G network architecture will be designed according to the access sites and DCs of the three-layer cloud, and SDN controllers will participate in its transport network, which will generate a series of specific data-based routing routes based on the topology of the network and the service requirements.

26 Terrestrial station connected to an antenna (or several antennas) that receives and transmits the signals in the cellular network
27 Key Performance Indicator Performance Meters.

6.4.Big data

When using the good features of SDN in a Big Data environment, it is expected to be able to benefit its applications in several visible aspects such as those shown in Figure 10, including: (1) Big data processing in Cloud DCs, (2) improvement in data delivery, (3) runtime programming for application optimization, (4) Big Data scientific architectures and (5) Hadoop programming[28] [54]. In this regard [55], [56], [57], [58], [59] include the benefits provided by SDN characteristics for Big data applications.

As explained in [55], where a Cloud DC based on SDN is studied for Big data applications, a model based on SDN / OpenFlow is established, with switches (CICQ)[29] and an App-RA[30], which allows an allocation of efficient resources and a reduction in energy consumption for each application within the DC.

In terms of data delivery, in [56] the authors propose a hybrid approach (optical and electrical) that takes advantage of the physical layer optics with an optical space sender switch (OSS), and the control provided by three receiver switches Top-of-rack (ToR)[31] of an electric packet switching network, to accelerate the delivery of each traffic pattern. The ToR switches were managed by the JGroups[32] application compatible with the SDF OpenFlow controller, which allows flexible and dynamic runtime configuration of photonic devices to support complex traffic patterns.

Also, in [57] Heller et al, DCs based on SDN are presented with an optimal topological composition and traffic load balance, implementing a dynamic system in traffic engineering (TE) with three components: A Datacenter network (DCN), an SDN controller and a TE administrator, specified in Figure 11.

The connection of ElasticTree aims at strengthening the network and allows a dynamic adjustment in the switches and links. It showed optimal results such as, reduction of energy consumption of 41% with a basic topology, and 60% less waste of active links, in comparison with the static scheme of the DC.

Figure 10. Characteristics of SDN that can benefit Big data applications, [54].

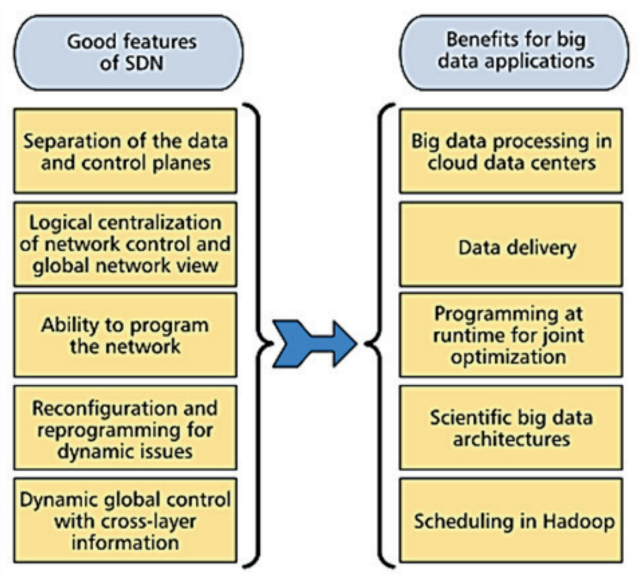
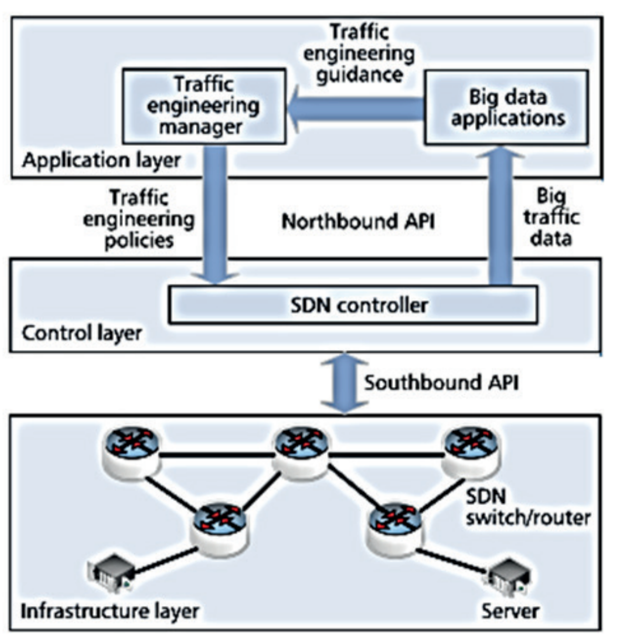


Figure 11. Architecture of dynamic traffic engineering system with SDN and Big Data Communication SDN-VANET, [54].



28 It is an open source system used to store, process and analyze large volumes of data

29 (CICQ) It is a combined input switch and a crossing queue. They are facilitated to be programmed by different applications that work in network layer.

30 Application-aware resource prediction: Scheme responsible for the prediction and allocation of resources for applications.

31 Top-of-rack switches used in high-density data centers

32 A protocol capable of comparing the end-to-end performance of a network architecture, by implementing a reliable multicast application on the end hosts

On the other hand, in [58] Inder Monga, Eric Pouyoul and Chin Guok, introduce the benefits of SDN to scientific models of Big Data architecture. Specifying a network architecture dependent on cross-layers and called OSCARS, which would work in environments where the continuous transfer of large amounts of information for scientific collaboration is necessary. This new hybrid network model manages multidomain bandwidth reservations, and end-to-end connectivity performance.

Finally, in [59], SDN is presented and its high impact on the performance of Hadoop systems. The growing trend is to consider Hadoop as a platform to help companies build more manageable DCs where Big Data processing emerges as an important part of the applications. However, it lacks a global vision for data processing and the correct allocation and dynamic bandwidth, so the model SDN in Hadoop (BASS) adopts the combination of SDN and Hadoop for the correct programming of jobs of Big data processing.

7. Organizations of Standardization

7.1.ONF

With the objective of promoting SDN, the ONF (Open Nerworking Foundation) was founded in 2011 [3], with a current participation of 150 members such as: computer companies, software, manufacturing of network equipment, service providers, among which It highlights companies such as Google, Microsoft, Juniper, Cisco, Verizon, among others. This non-profit organization participated in the standardization of the OpenFlow protocol, which was born as a research project of Stanford University and of which Martin Casado also took part, addressing the requirements of a diverse range of devices adapting them to open source specifications., [16]. In 2017, it finishes the merger with ON.Lab, responsible for the development of the SDN ONOS platform, as well as the SDN / NFV case most deployed in carrier networks called CORD (Central Office Re-architected as a Datacenter). Finally, in 2018 the community P4 [60], [61], which emerged at Stanford as an OpenFlow improvement for data plane programmability, also joins ONF.

7.2.IRTF and ITU

The Software-Defined Networking Research Group (SDNRG) of the IRTF [62] was also in charge of working on the fundamentals and specifications of the SDN, until 2017, when the activity of the group ceased. In RFC 7426 they define the SDN architecture with few differences with respect to the one currently defined by ONF.

Similarly, ITU also has a working group regarding SDN [63], although with little activity compared to the ONF.

7.3.ETSI

ETSI moreover carries the main weight in NFV standardization, although a large part of its documents are recommendations. The activities of the organization began in 2012, with the Industry Specification Group (ISG), founded by seven operators of international telecommunication networks. In addition, similarly to ONF with ONOS, ETSI is in charge of the development and evolution of the main Open Source NFV platform, called Open Source Mano (OSM) [64] and in which more than 100 organizations, including operators, participate, manufacturers, small companies, research institutes, and universities.

8. Conclusions

In this article, a review of the most relevant categories of the SDN paradigm has been carried out, by creating a frame of reference for future research. For this, the description of the architecture components was made, contextualizing the reader of the importance and functionality of each of these components. The various instances of SDN use in technological trends such as: IoT, 5G, Big data, and modernization of data center management were also documented. Likewise, we show some of the most renowned controllers in the market, specifying in their development, main characteristics, contribution to SDN, and degree of compatibility with other protocols. Additionally, the concept of NFV was included in a general way and how, through its contribution of virtualization, it complements the SDN paradigm, allowing cost reduction and greater deployment than in traditional networks.

Finally, the main standardization institutions such as ONF, IRTF, ITU and ETSI were chosen and mentioned and they have worked on the deployment, development, and standardization of SDN.

It is interesting that the literature review of the subject shows a scarcity of literature in Spanish-speaking countries, therefore there is an opportunity to continue exploring research that demonstrates the adoption of SDN networks and all the challenges that it faces.

As future research on the subject, the opportunity for the SDN market appears, motivated by the increase in resources demanded by the different technological trends, which include BYOD ("Bring Your Own Device") it frames new challenges to achieve greater security [65], developing solutions that allow the deployment of SDN, providing mobility, management, and monitoring of the devices that have essential information of the organizations, [66].

On the other hand, SDN has a great opportunity to achieve a transcendent change in the administration of the current networks, which starts from the good provisioning of its APIs, [67], for a greater simplicity in its control and proceeds with the reduction of infrastructure physics for greater visibility and cost advantage.

It is important to mention that in organizations such as the ITU, ITRF and ETSI, there is not information with developments in the category of relevant regulations, because the ONF has led from the beginning the process of SDN regulations. Furthermore, about 42% of the references are for applications and cases of use of the SDN paradigm, so it is clear that there is evidence of the applicability and benefits of SDN in several communications network market environments.

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