Software-Defined Optical Network (SDON), new generation networks

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Abstract. At the time of establishing communications, the configuration of network resources, storage and computer systems worked independently. With the innovation and the new communication alternatives, the management was initiated so that all the parts mentioned above work together. This is how the idea of virtualization emerged, a process by which virtual versions of computers, operating systems and applications are created. For all network devices and servers to communicate with each other and function correctly there must be a centrally functioning controller, this is when a promising SDN paradigm emerges; networks defined by software considered as a promising method to rebuild the Internet architecture and improve the implementation and distribution of applications in communication networks. In addition, we will discuss how SDN networks perform their inclusion in optical networks, study these advanced architectures, in order to facilitate flexibility and resource optimization in optical transport.

1. Introduction

The increase in communication networks, the thousands of data transmitted and the constant use of the network, require improvements in service and resources that are part of it, in addition to avoiding the various causes of performance impact such as packet loss, latency, bit rate and network congestion [1]

The main characteristic of software-defined networks is the separation of the control plane from the data plane, the first is responsible for managing the necessary resources of the network with their respective traffic and the second is composed of different network devices, transmission media and different services.

On the other hand, SDN creates networks that work with the centralized control of a software application, which eliminates the need to use specifically designed network devices; in this way a network administrator can shape traffic from an SDN controller without having to touch individual network devices.

The decisions on the transmission path of the network flow, in addition to the configuration of the network infrastructure from a centralized application, are made by the SDN, which is responsible for responding efficiently to the data plane, taking into account the status and requests of the application plane. These decisions taken from the control plane are communicated to the data plane with the necessary actions to be carried out on the network infrastructure. Each plane of the SDN has its specific functions and communication protocols [2].

The Open Networking Foundation (ONF) is in charge of developing protocols or open standards that allow the implementation of SDN. Within the control protocols implemented in software defined networks, the Borden Gateway Protocol (BGP) used to exchange routing information between gateway terminals in a network of autonomous systems is identified. Each network has a router and its respective network information such as routing tables that store the routes of the different connected routers, the ip addresses that can be reached, in addition to a cost metric associated with the route to choose the best...
and available [3]. Also, there is the Netconf protocol used for the secure administration of the network, opting for the remote procedure call that is used to solve the different inconveniences present in the configuration of the network devices. Additionally, there is the MPLS Transport profile protocol (MPLS-TP) which was designed to be used as a network layer technology, as a connection-oriented packet switching application (CO-PS,) dedicated to eliminating features that are not relevant in CO-PS applications and add devices for critical transport. The purpose of the ONF is to develop an architecture that allows full control from a software controller and manages the operation of the network [4].

The OpenFlow protocol makes it possible to coordinate the routes for sending packets from one terminal to another, in addition to administering and programming the network as a whole, since in the control plane the decisions for migrating packets in the data plane are centralized. We chose this protocol because its use extends to optical networks, has been developed to allow the virtual allocation of network resources from various levels of granularity. In the application plane can require or dynamically control network resources wavelength, circuit, flow in granularity to seamlessly reconfigure resources based on the requirements of the application plane [5].

2. Software Defined Networking

Before entering SDN, let's remember the traditional networks. A data network is the set of network devices organized in a hierarchical way and interconnected with each other through a means of transmission that allows the exchange of information and resources. Each network and terminal device that is connected to the network, manages its own configuration and preset policies that define the tasks of each device, as well as what it must do with the data or information that passes through it, this configuration is done before the network operates.

SDN, is a paradigm that allows the control of the network infrastructure located in the data plane intelligently, implements the use of centralized software with which manages the network functions, carries out a centralized and distributed control of the network, for this reason the control plane and the data plane must operate independently [6].

In the past, the network administrator had to configure each independent device belonging to the network, a rather complicated and inflexible task for companies with large networks. It is now in charge of traffic management by means of controllers with which an efficient flow of the network can be obtained, which will be able to respond to all the needs that arise during its operation [7].

In SDN the packet forwarding is controlled by an interface, the way of processing the packets is no longer fixed, each packet can be handled separately and managed by the control plane, by a controller that is responsible for meeting the requirements of performance, scalability, flexibility and agility necessary for Internet communications [8].

To summarize the elements that characterize SDN are:

- The control and packet switching functions are separated.
- The functions of the control plane are centralized in a single node, in which the data traffic routes are configured.
- Network traffic control, SDN can share network traffic between several servers without having to create a system that is capable of supporting this traffic.
- The functions of the control plane are implemented in a controller or software, which manages the separation and coordination of network traffic.
- Any type of software can be developed for the network.
- The network administrator can make modifications or verify novelties in an efficient way, since it performs permanent monitoring of the network.
- It enables and promotes the development and use of routing algorithms to exploit network capacity.
2.1 Data Plan
This plane consists of network devices or terminals that form a data network and perform certain tasks depending on the functions defined by the logical components of control and data.

In the control is the state of the network that is communicated to the controller, which simultaneously indicates the routes for packet forwarding, these routes can be optimized by implementing routing algorithms. In the data, the network devices forward the packets according to the decisions made by the control plane. The first packet of a data stream is sent to the controller for processing of the packet, in order to update the routing tables and send the packets according to it [9].

2.2 Control Plan
Within this plane the most important thing is the controller, since it is in charge of managing the application and infrastructure plane, centralizing the monitoring of all the devices of the network. On the other hand, this plane is in charge of the communication with the SDN applications and the data or infrastructure plane.

The control plane communicates with the application plane and translates the requested requirements, as well as collecting all the information concerning the data plane and displaying it in the application plane.

At the same time, as previously mentioned, the control plane through communication with the infrastructure plane, is the one that collects the state of the network and according to the requirements of the applications, the control plane updates the route of sending packets in the devices [9].

2.3 Application Plan
As mentioned above, one of the main features of SDN applications is to communicate requirements to the network through the application programming interface (API), which is located between the application plane and the control plane, and is designed to facilitate user interaction and meet the needs of users [10].

Separation of two planes: data plane and control plane.

The data plane performs a sequence of tests and verifications on the datagrams that travel at the link level and are responsible for verifying that the data is adequate. If the datagram is incorrect, the package is delivered to the controller to decide what to do with it. If it is correct, the FIB (Forwarding information base) operates to see what the destination of this data is, since the FIB is used in the forwarding of packets.

The control plane consists of several local data that allow you to create the packet forwarding table called RIB (Routing information base), which are used by the data plane to manage network devices.
The RIB exchanges information all the time to keep up to date. After the RIB we have the FIB, but this comes into operation when the RIB is stable. The RIB is used in the control plane and the FIB in the data plane [11].

This type of searches improve the performance in the forwarding of packets, searches that are very desired for services with a large bandwidth. To facilitate this sending of packets, the datagram has a header, thanks to it can also facilitate the search time, identifying much faster the destination of the packet.

2.4 OpenFlow Protocol
This protocol emerged at Stanford University and seeks the separation of the control plane and the data plane, the standardization of protocols between network devices and controllers, from a centralized API we can promote the programmability of the network.

For this protocol to work, this architecture proposes the existence of OpenFlow switches. This is formed by flow tables that are managed from the controller and an external channel that connects to the controller. The controller manages the behavior of the switch through the secure channel using the OpenFlow protocol [11].

The controller can add, update, and delete information from the flow table, both reactively (in response to packets) and proactively (generating actions).

Each flow entry works in the following ways:
- Send the packet flow to a respective port.
- Encapsulate and send the packet stream to the controller for him to decide what to do with it.
- Override the packet flow for security.

![Software Defined Network Architecture](image)

**Figure 2.** Software Defined Network Architecture [9]

3. Software Defined optical network
We have already carried out a brief review of the networks defined by software. Now they are, because they are included in optical networks. Optical networks offer too many advantages over conventional networks, since they offer greater capacity, high scalability and low power consumption. The single
fibre transmission capacity has exceeded 100 Tb/s, the 100 Gb/s per channel wavelength multiplexing (WDM) system is being implemented and the superchannels handle a data rate of 400 Gb/s or 1Tb/s [12].

Optical networks handle data traffic, which allows SDNs and particularly the OpenFlow protocol to support and integrate multiple network technologies. In 2013 the Open Network Foundation (ONF) created the Optical Transport Working Group (OTGW) teaches the benefits of extending software-defined networks and the Open Flow protocol into optical transport, including flexibility in network management or administration, improved control of optical transport network, implementing new virtualization services and systems control [13].

Packet switching in conventional networks is less scalable than switching optical circuits that can change to higher granularity, the optical circuit consumes much less energy than the packet switch that is growing by the volume of traffic, in addition the combination and filtering of basic operations of optical signals are completely passive. Software defined optical networks have similar characteristics to SDNs, such as: network management and administration from centralized control, and network devices in the infrastructure plane offer high flexibility to support different network conditions.

The structure of the optical networks defined by software, exposes 3 main elements. The application plane, the highest plane of the structure, allows the end user from a control application to apply changes to the network without any inconvenience. This plane communicates with the next plane, through an API that facilitates interaction with the control plane, which is characterized by having a centralized controller that manages the network, improvement and custom through software that allows optimizing energy, resource allocation and protection.

And finally we have the data plane, where there is the programmable optical hardware, including transmitters, receivers, modulators, couplers, filters, amplifiers, switches, among others. These devices perform operations such as transmission, modulation, elastic bandwidth commutation, allow to establish the optimization and management of SDON. As in optical transport the main functions are transmission and switching, it is important to have two important optical network devices in SDON [14].

![Figure 3. SDON Architecture.](image-url)
The Flexible Switch is considered a reconfigurable optical insertion and extraction multiplexer (ROADM). It is responsible for switching any output port, has multiple ports, in addition, have the wavelength conversion function and the ability to fully switch data streams in the optical domain. ROADM is applied to SDON providing flexible switching, which allows you to adapt to different types of signals without additional problems in costs or signal quality. As described, the main features are:

- No filter: The transponder does not need an optical demultiplexer or filter to dynamically select the WDM channel from the flex-grid.
- No Grid: The channel bandwidth can be dynamically varied to accommodate variable transponder signals.
- No channelization: Adjacent WDM channels can be grouped into wavebands that can be switched.
- No connection: Signals with the same wavelength can use different simultaneous inputs and outputs.
- Colorless: ROADM can extract or add any wavelength from the transponder.
- No direction: The transponder receives an extracted input signal or adds an output signal.

Another important device is the variable transponder, a device used in telecommunications as a receiver and transmitter of signals. Signal characteristics such as data rate, modulation format and correction coding can be dynamically changed for WDM channels from the transponder. Various schemes are found to achieve the above-mentioned features:

- Digital transmitter: high-speed digital signal processing is used in real time for data modulation format, then the optical signals are modulated in phase and quadrature through electro-optical modulators. Additionally, it has a coding of errors that allows you to correct them are in need of more resources.
- Variable format transmitter: An O/E/O signal generator and cascade optical modulators are used to select between QPSK, QAM, taking into account spectral efficiency.
- Variable Transmitter: Optical orthogonal frequency division multiplexing is used to create high capacity superchannels.

We use flexgrid and elastic rates to supplement the above-mentioned features. Flexgrid allows adapting the bandwidth in a heterogeneous way according to the demand; in addition, the ITU must establish a new recommendation for the thinnest frequency slots, where the spectrum of an optical channel includes several frequency slots.

The Elastic Rates dynamically adjust data rates by adjusting modulation formats and the number of subcarriers. The elastic transponders used are defined by software, allowing the flexible allocation of sufficient optical bandwidth according to the current traffic demand, which is an advantage, since it speeds up the transport in optical networks.

It is as we see here, the joint work between optical networks and SDN, where centralized control based on SDN, is necessary for adaptation to the characteristics of the flexible optical layer, where some specific functions are included:

- Flexible allocation of network resources: from the SDON controller the allocation of network resources is programmed in a flexible way to achieve performance optimization.
- Spectrum optimization: SDON uses routing algorithms for wavelength assignment and spectrum assignment to optimize spectrum utilization taking into account demand, network status, required transmission speed, and the appropriate light path for transmission.
- Network defragmentation: Several researches are known to develop network defragmentation algorithms, which have the capacity to consolidate the spectrum and reoptimise the use of network resources.

4. Viability and relevance

At present, several routing and wavelength assignment (RWA) algorithms have been proposed in optical network studies, but they have the disadvantages of assigning a specific wavelength and a fixed bandwidth for each connection. Meanwhile, in the routing and assignment of spectrum, a central frequency and a variable bandwidth are assigned depending on the requirements of the service.

Due to the above, is motivating the study of routing and spectrum allocation (RSA), which has emerged as a way of offering an efficient use of available optical resources, hand in hand with networks.
defined by software. Which can solve the problem of routing; the calculation of routes between the source origin and destination through a centralized controller, and additionally the allocation of spectrum could be worked through artificial intelligence techniques.

Bearing in mind that the implementation of optical networks defined by software is a clearly new subject, a feasibility study was carried out identifying the limitations, opportunities and assumptions of the same. With regard to the limitations in the development of the solution presented, the limitation was found in the testing and implementation of an optical network defined by software in real environments, since there is no technological network infrastructure to perform such tests, therefore, has opted for the use of simulators and network emulators such as Omnet++ and Mininet. The first, allows the modular simulation of discrete events in networks, programming is object-oriented, the second allows creating a realistic virtual network on a single machine, running real Kernel, since it is done through CLI. The opportunities of the study, are the development of algorithms of assignment of wavelength, spectrum or routing that allows to speed up the configuration of the optical networks and likewise to solve the main disadvantages as the speed of bit, loss of packets and latency.

5. Future jobs
This is the beginning of the development of the end-of-master project "To develop a dynamic spectrum assignment method for flexible optical networks defined by software, using artificial intelligence and performance quantification techniques, in order to optimize the use of spectral characteristics". Bearing in mind the increase in network traffic and the demand for new telecommunications services that require high bandwidth, the aim is to avoid wasting bandwidth by increasing network capacity, reduce the complexity of network elements and improve network reconfigurability with software-defined optical networks (SDON), since this way large volumes of information can be transported quickly and securely but with relatively small computational efforts. The algorithms will be tested in the Omnet++ network simulator.

6. Conclusion
In this work a partial description was made of the networks defined by software and their development process and incorporation into optical networks. Since they are considered new generation networks, since they have design features with the separation of control functions, transport and services, they are considered open interfaces, they have planning and integration of services and maintenance and integration with current networks. The most relevant characteristic in optical networks are the centralized controllers based on SDN and the development of routing algorithms for the assignment of spectrum and wavelength, since from them an intelligent control can be carried out that allows network administrators to improve the management and distribution processes of the network. Additionally, from the control plane a protection scheme can be centralized and thus guarantee the stability of the network. From another angle, we have optimization in optical transport, given that there is flexible allocation of bandwidth depending on traffic demand. SDON therefore has great potential and a promising future in the development of telecommunication networks.

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