Optimization of a WiFi Wireless Network that Maximizes the Level of Satisfaction of Users and Allows the Use of New Technological Trends in Higher Education Institutions

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Abstract. The campus wireless networks have many users, who have different roles and network requirements, ranging from the use of educational platforms, informative consultations, emails, among others. Currently due to the inefficient use of network resources and little wireless planning, caused by the growth of the technological infrastructure (which is often due to daily worries, rather than to a lack of preparation by those in charge of managing the network), There are two essential factors that truncate the requirement of having a stable and robust network platform. First, the degradation of the quality of services perceived by users, and second, the congestion caused by the high demand for convergent traffic (video, voice, and data). Both factors imply great challenges on the part of

N. Streitz and S. Konomi (Eds.): HCII 2019, LNCS 11587, pp. 144–160, 2019.
https://doi.org/10.1007/978-3-030-21935-2_12

the administrators of the network, which in many occasions are overwhelmed by permanent incidences of instability, coverage, and congestion, as well as the difficulty of maintaining it economically. The present investigation seeks to propose a process of optimization of the infrastructure and parameters of the configuration of a wireless network, that allows maximizing the level of satisfaction of the users in Higher Education Institutions. In the first place, it is expected to determine an adequate methodology to estimate the level of satisfaction of the users (defining a mathematical criterion or algorithm based on the study variables [1], characterize the environment in which the project will be developed, making a complete study of the wireless conditions and implement optimization strategies with software-defined networks (SDN). SDN is a concept in computer networks that allows network management to be carried out efficiently and flexibly, separating the control plane from the data plane into network devices. SDN architecture consists of an infrastructure layer which is a collection of network devices connected to the SDN Controller using protocol (OpenFlow) as a protocol [2]. Also, SDN will study traffic patterns on the network as a basis for optimizing network device usage [3]. The phases of the research will be carried out following the life cycle defined by the Cisco PPDIOO methodology (Prepare, Plan, Design, Implement, Operate, Optimize) [4].

Keywords: Software-Defined Networks SDN · Wireless Networks · Optimization · PPDIOO · Higher Education Institutions

1 Introduction

Currently, many institutions of higher education have a technological platform that offers a large number of services to students and teachers, which facilitates the teaching and learning process. Within the services provided by students and teachers, there is total access to the Internet, access to virtuals queries in databases and specialized bibliographic resources, access to software and applications on the web, online consultations of notes and activities to develop, etc. These services place educational entities at an advantage since tools and technological means are currently used and are involved in all aspects of daily life. In some institutions of higher education, it is possible to identify the shortcomings in terms of services at a technological level that offers students, professors and members of the institutional community, due to several factors such as the lack of resources to improve the infrastructure of the Reduce, there are planned, connectivity problems, day, day, misuse, resources, media, etc. protocols.

The fact of not having connectivity and total access hinders communication and the development of any activity or work that you want to do with the use of technological tools such as smartphones, tablets, and laptops at any time when the student or teacher is inside of the campus. Given this problem, disinterest in the use of virtual resources offered by the institution is encouraged. The purpose of technological tools in learning environments has become indispensable since they allow interaction in real time. Hernandez et al. [5] in their research on the use of the Internet of Things in the Higher Education Institutions of the city of Barranquilla, made a preliminary diagnosis of the state of the network infrastructure, both wired and wireless, of the leading universities of the city. Only some institutions have adequate technological platform and of which their users have a high level of satisfaction. The vast majority, according to the study, have the flaws already mentioned. On those campus sites where connectivity is inefficient, slow and intermittent according to what is expressed by members of the educational community, it is essential to take some action to improve wireless access.

With the purpose of promoting technological growth in Higher Education Institutions, it is necessary to optimize the wireless network platform or infrastructure, which is capable of efficiently managing the network services offered by the institution and which maximizes the level of user satisfaction. The optimization (and probable implementation in some parts of the campus) of this platform will allow the connectivity and total access to the internet and to the different applications of any person that is inside the institution and that is involved in some process of this. The paper is structured in the following way, first the introduction that has just been specified. The second section shows previous research and the state of the art of the project. The third section emphasizes the research methodology used. The fourth section shows preliminary progress and discussion about the results. It culminates with the conclusions and future work to develop from this work.

2 SDN and WLAN Optimization. A Literature Review

In this section we analyze the existing context in the scientific community and related projects about optimization processes of wireless network infrastructure, using a new trend as SDN. With regards to wireless network optimization, several studies have been carried out [6, 7]. Cisco in its material of the Networking Academy [8] highlights the following essential points about the data network: among all vital elements for human existence, the need to interact is just after the need to sustain life. Communication is almost as important to us as air, water, food and a place to live. The methods we use to share ideas and information are continually changing and evolving. The immediate nature of Internet communications encourages the formation of global communities. These communities motivate the social interaction that depends on the location or the time zone. Being able to communicate reliably with everyone everywhere is vital for our personal and business life. To support the immediate delivery of the millions of messages exchanged between people around the world, we rely on a web of interconnected networks.

A novel and innovative way to optimize the wireless network infrastructure is through the implementation of a solution based on SDN, or networks defined by software. SDN enables organizations to accelerate the deployment and deployment of applications by dramatically reducing IT costs through the automation of policy-based workflow. SDNs converge the administration of network services and applications into centralized and scalable coordination platforms that can automate the provisioning and configuration of the entire infrastructure. In our academic environment, there has been no research related to this issue, let alone a solution for network optimization, whether wireless or wired, based on this new approach. About SDN several essential investigations have been carried out. Sezer et al. [9] in their research explain the fundamentals of SDN and the impact it will have as a future paradigm for the implementation of networks. Jammal et al. [10] present a series of references and important works about SDN and its application for the optimization of connectivity infrastructures. The ONF (Open Networking Foundation) [2] defines SDN as “an emerging architecture that is dynamic, manageable, cost-effective and adaptable, making it ideal for the high bandwidth required by the dynamic nature of today’s applications.” Figure 1 shows the SDN Architecture:

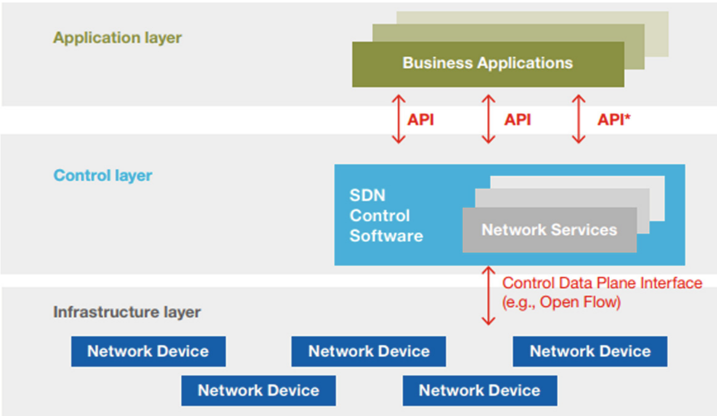

Fig. 1. SDN architecture

Entering SDN, we analyzed the theories related to the topic. Beginning with Bakshi [11], explains that SDN is a new approach to the design of the network, based on the ability to programmatically modify the behavior of network devices. Poses that SDN will provide many benefits to the organizations that implement it since it will allow networks to be more flexible, dynamic and cost-efficient.

Internet of Things (IoT) is a new trend that raises the total connectivity of all devices that can be imagined, using sensor networks, fixed wireless, and mobile solutions, among others. Wifi solutions based on the new IoT trend, in conjunction with SDN, are also susceptible to optimization. Baird et al. [12] in its research, aims to use an approach based on SDN with captive portals and the use of the 802.1X security standard to control access to the network by intermediary or final devices, in such a way that the congestion that may arise in the network does not affect the performance of the same. However, there are also some studies that consider it not so convenient to make a complete migration, but gradual, from the traditional scheme of supervision, monitoring, control and optimization of conventional networks to SDN. Studies such as the one conducted by Sandhya et al. [13], raises some reasons for a gradual transition to SDN. Among these reasons, because the hybrid environment allows SDN and legacy equipment or nodes to coexist, which facilitates the development of an incremental implementation strategy. The hybrid solution provides adaptability to the budgetary conditions of an organization, the programmability of the network, the recovery of mechanisms inherited over time, among others.

Continuing with the line of hybrid SDN solutions, Amin et al. [14], in its research, aims to show different updated studies related to research and development of hybrid SDN networks. Haruyama [15] gave one of the first definitions of SDR to implement SDN oriented wireless networks, he explains "Thanks to the recent advancement of semiconductor technology, it is now possible to process high-speed communication signals in wireless telecommunication systems using as much digital technology as possible.

Other research related to the integration and interaction between IoT, SDN and wireless communications is carried out by Bedhief et al. [16], whose objective is to present the results of the implementation of an SDN controller in conjunction with the MiniNet emulator, to test the connectivity of heterogeneous devices, beyond the heterogeneous wireless networks in which these devices can operate (Ethernet, WiFi, ZigBee, Bluetooth). The difficulty involved in the administration, control and programmability of networks and IoT applications such as Smart cities, Smart Healthcare, Smart Industry, etc., based the research. In the previous reference, the authors use an emulator called MiniNet to make the tests and build their architecture. Fontes et al. [17] in their work, explain in that the objective is to emulate SDN/OpenFlow scenarios that allow high fidelity in the experiments that researchers need to execute to test SDN architectures, to recreate real networking environments. The strengths of the emulator and its limitations are exposed, and they even present three cases of study in which different tests were made. MiniNet arises given the new features of current wireless networks, in which the density of users, the number of base stations and customers, and high traffic rates require the design of cost-effective wireless networks, which have efficient use of resources and ease of administration, due to the challenge involved in managing this complex type of solutions, including IoT applications.

In addition to the emulator mentioned above, other technologies work hand in hand with SDN to manage mobility in IEEE 802.11 WLAN networks. Gilani et al. [18], present the benefits of joint work between SDN and NFV (Network Function Virtualization), for the optimization of traditional wireless infrastructure, the primary objective of its research. A study focused on the control plane of the infrastructure equipment that facilitates virtualization and network administration was carried out by Blenk et al. [19] in their research. The authors explain that hypervisors are logically located between the multiple virtual SDN networks (vSDN), which reside in the SDN physical network infrastructure, and the corresponding tenant controllers (vSDN).

3 Methodology

The following types of research are defined, based on what was pointed out by Hernandez Sampieri et al. [20]:

- According to the object of study: For the execution of this project and according to the problem, it is necessary to use two types of research. First, exploratory research, because innovation is an essential support for the project; therefore, some critical aspects of its development are unknown. As the second type of research, we have applied research, because it is proposed to solve a practical problem of the environment, in this organizational case (maximizing the level of satisfaction of the users of the wireless network, defining an optimization process of the Wireless infrastructure).

- According to the level of measurement, scientific knowledge, and information analysis:
  - Quali-quantitative: because it is based on a working hypothesis, defined in how to maximize the level of satisfaction of the users of the wireless network, optimizing the configuration parameters and the infrastructure of the Wireless network through SDN, to which by means of a proposed process and with a series of procedures, it is intended to provide a solution, evolving with the course of the study.
  - Descriptive: since all the documentation related to optimization and designs of wireless networks will be reviewed, SDN implementation, solutions that have already been provided with advanced wireless equipment and contribute to the scientific literature on the subject based on what was compiled.
  - Correlational: It is intended to visualize how a variable can behave knowing the behavior of another related variable and evaluate the degree of relationship between them, that is, cause-effect analysis between independent and dependent variables will be performed.
- Research design. The present project is part of the experimental design type, considering the collection of the necessary information to answer the research questions, since a series of experiments will be carried out, testing each one of them, and verifying the respective results of each.
- Phases of the project. For this research, the life cycle defined by the Cisco network design methodology, PPDIOO, will be adopted, explained by Oppenheimer [4]. As shown in Fig. 2, PPDIOO consists of five stages:

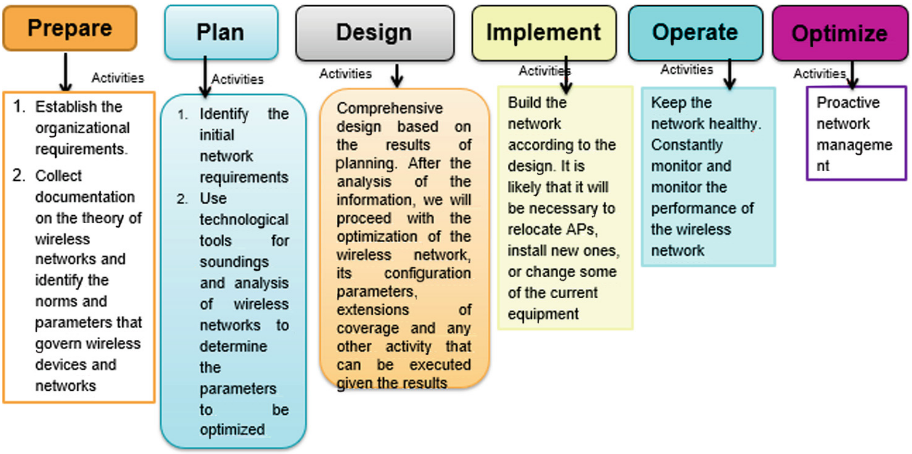

Fig. 2. PPDIOO life cycle

4 Results and Discussion

The project is in the design phase of a network topology that allows optimizing the performance of the wireless infrastructure. The results to present will be those collected by a survey to measure the level of satisfaction of users for identified service variables. Likewise, the results of the site survey and response times of the current network will be exposed, as well as the design of the simulated topology in the Mininet tool, on which tests like those performed in the existing network will be executed. The next phase of the project is to establish the gap between both measures to conclude which solution is more favorable and, in this way, provide the recommendations of the case to the directors of the University for the acquisition of network infrastructure equipment that enhance the performance of the same. The current infrastructure does not support SDN, so it cannot be implemented, and no more real measures can be taken. However, Mininet is a test very close to the actual implementation and can serve as a support to justify the investment.

A. *Network Topology. Current Network Vs. SDN Simulation*

Figure 3 shows the current network topology of the University:

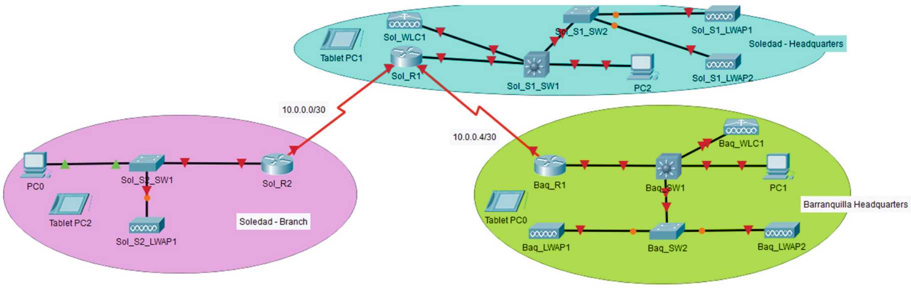

Fig. 3. ITSA current network topology – all venues

Each site has a set of defined VLANs, among which is a VLAN for the wireless network. The internal routing protocol of each site is EIGRP, and between sites is BGP. The headquarters of Soledad Headquarters and Barranquilla have each a wireless controller and some autonomous WAPs. Several tests of the wireless network were taken, among which are: coverage, response time, SSIDs, RSSI, use of bandwidth. The measurements made in the Library serve as an example. Figure 4 shows a high number of SSIDs in the area, channel, RSSI and security algorithm implemented:

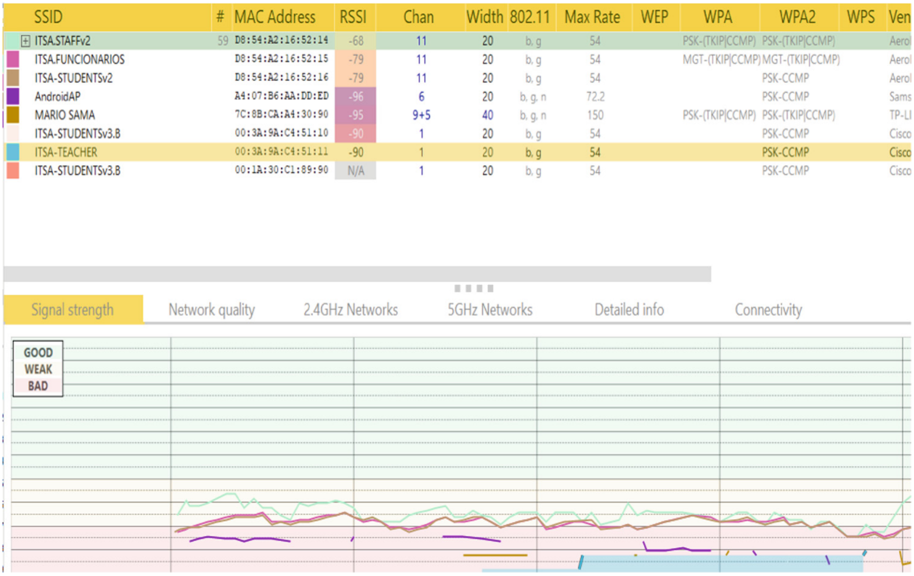

Fig. 4. Site survey – library

As you can see, there is a high RSSI in each SSID, which means that the wireless network in this area is presenting high congestion and intermittency. Figure 5 shows that the overall network quality is poor:

Figure 6 shows that there are SSIDs that overlap each other, which affects the performance of the wireless network in general:

Figure 7 shows a graphical ping to the gateway. It is possible to see the intermittence and instability of the ping, from a wireless client:

On average, the approximate round trip taken with the ping is 130 ms, which is too high for a traditional wireless connection. This same behavior is reflected in the vast majority of the campus (in each location), for which it is essential to make an optimization. The project proposes to measure the performance that an SDN solution can give in a simulated environment, which will give a good measure of the possibility of migration of the current infrastructure.

Figure 8 shows the topology of the network designed with SDN:

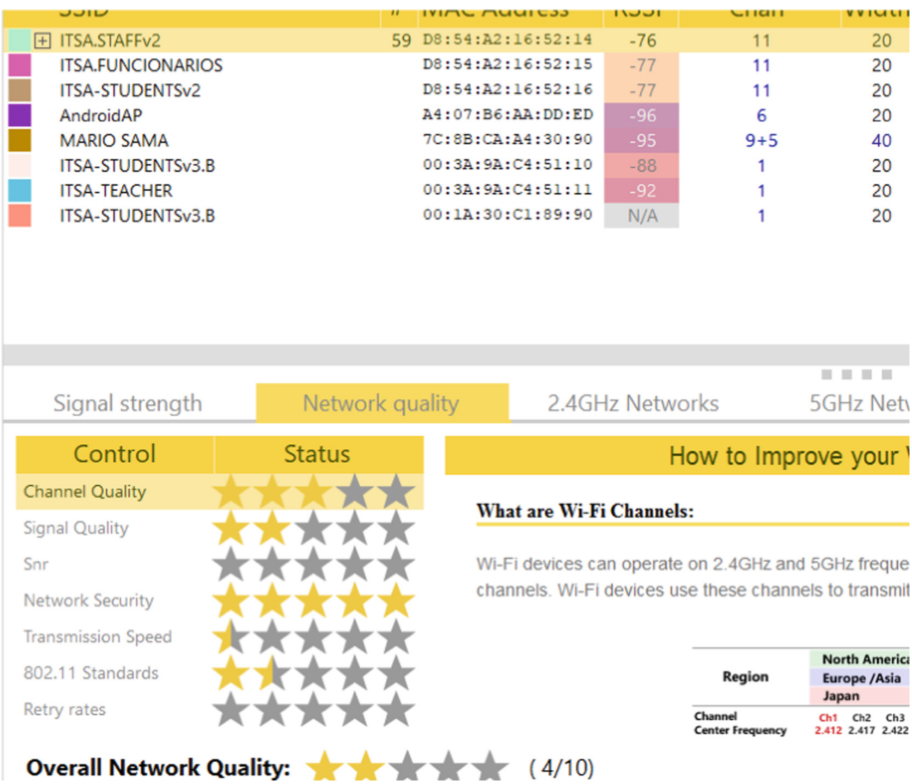

Fig. 5. Total network quality

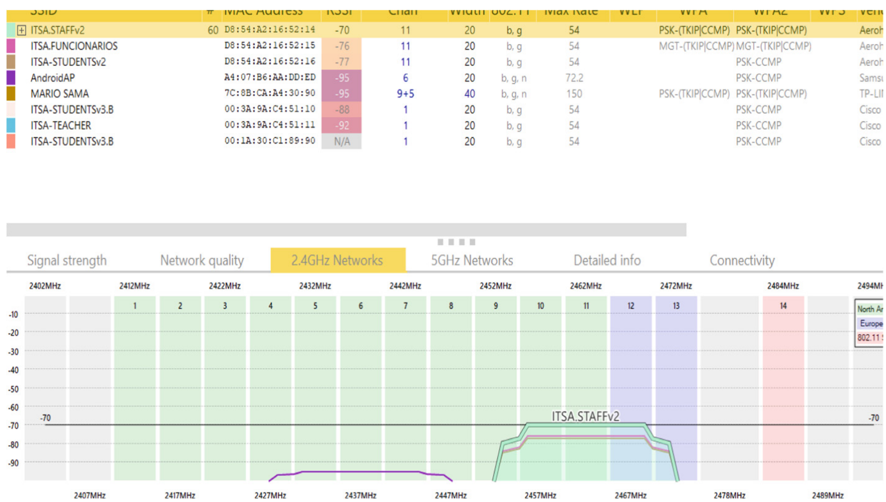

Fig. 6. Overlapping between SSIDs.

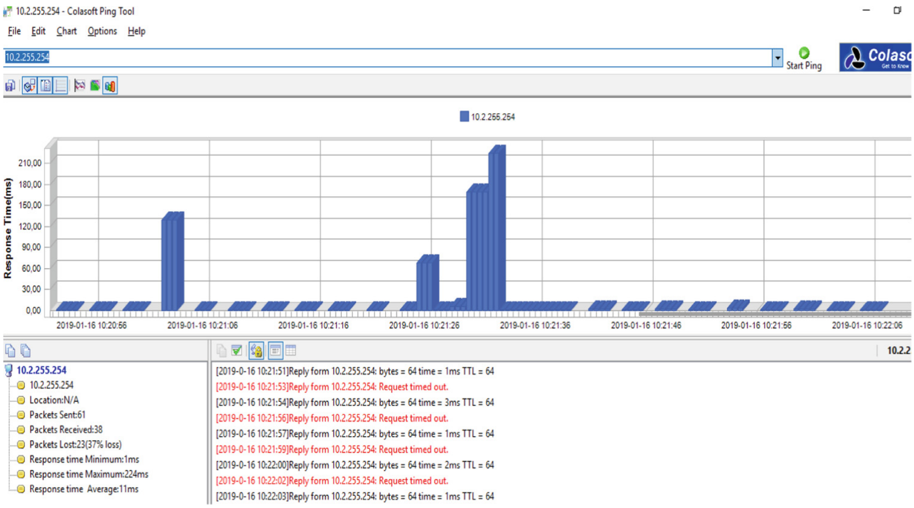

Fig. 7. Intermittence of a ping

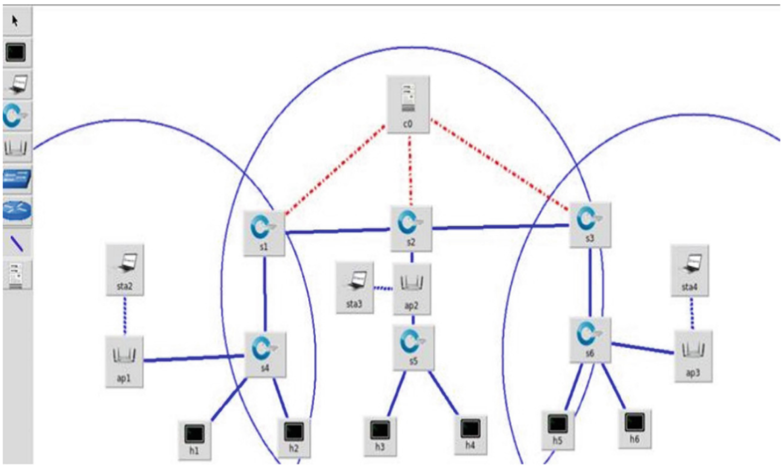

Fig. 8. Network topology – SDN design

The following solution is proposed: there is a single controller that will monitor the behavior of the three sites and all connected devices, including wireless equipment. The traffic behavior between each site is configured through the controller, thus optimizing network response times and overall performance. It is advisable to have an additional backup controller, but it is not included in the design due to its high cost. In this topology, S1, S2, and S3 are the primary switches in each site. At this moment we are testing this topology, there are still not enough results to establish a comparative analysis of the performance of the SDN network concerning the traditional network topology, which is expected to have a short term.

B. *Results and Analysis of Statistical Measurement Instrument.*

A survey was conducted to measure the level of satisfaction of the users of the institution's wireless network, to determine the factors that most affect, and review the parameters that most affect the behavior and expectations of the users of the network. Each question is a variable, which will be shown coded later.

As an initial result of the factorial analysis of multiple correspondences, using software R version 3.5.0, a two-dimensional graph was obtained, which shows the relative positions of the variables that allow measuring the satisfaction of the users for the internet service, as shown in Fig. 9, with which the classification of the observations or individuals was made, through the Factors Map provided by the software R, considering how the individuals responded to the questionnaire. The two dimensions of the survey, collect 21.21% of the variability in the answers obtained.

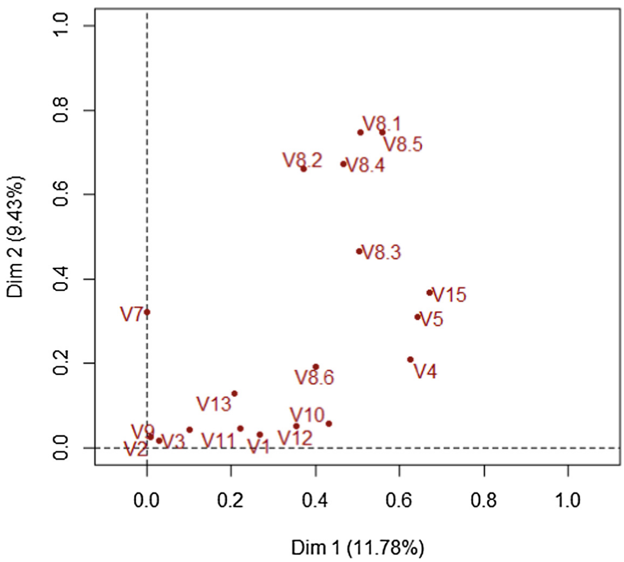

Fig. 9. Two dimensions. relative position of variables

Figure 10 shows three groups of observations or cluster can be identified, from which different groups were obtained taking into account the correspondences in the answers provided when applying the survey:

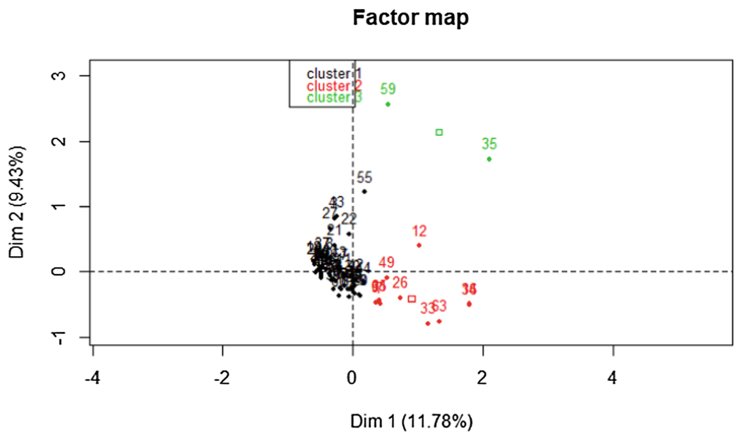

Fig. 10. Factors map

The first Cluster (C1) is made up of 50 individuals, corresponding to 79.37% of the total sample, of which 11 students from Telematics Engineering, 7 from Industrial Engineering and 32 from Technique in Industrial Electronic Maintenance are part. In this group, students are relatively satisfied with the Internet service of the university campus, which are characterized in general terms, for their reasonable satisfaction concerning the technical characteristics and services associated with the provision of Internet service on the university campus. They are mostly students of the Electronic Maintenance Technique program, but it is also made up of people from the Engineering programs, especially Computer Engineering, who know about the technical specifications of the service, 72% of the participants use the WiFi network Frequently.

Among the standard variables of the reasonably satisfied cluster are the regular ratings on the technical characteristics of the internet service, such as speed, availability, signal coverage, response times, real-time connection, stability and network security, as well as other variables evaluated in the survey, which were common, as shown in detail in Table 1. For this group, the current technological infrastructure that supports the Internet service is subject to improvement, given the regular qualifications of both the technical characteristics and the attention provided by the Technology staff, which is reflected in the regular levels of satisfaction in the service. So, it is necessary to focus action plans towards the optimization of infrastructure and quality in the service for the internet service. It is also vital that the processes carried out by the university for the improvement of its technological infrastructure be disseminated since 60% of the participating students do not know about these processes, activities, and progress in this regard.

Table 1. Common variables cluster 1

Technical variables	• 58% of the students in this cluster believe that the speed of connection to the wireless network is regular • 94% of individuals consider that the current technological infrastructure is susceptible to improvement • 42% of the students rated the availability of the Wi-Fi network as consistent, and 52% of the students rated it as regular to poor • 32% of the students consider how to regulate the coverage of the signal; that is, they can not connect from all points of the university campus. • 40% rated the response time of the network as regular, that is, presented delays • 42% of the students rated as regular the connection in a real-time of several users • 38% of the students rated the stability of the wireless network as regular, that is, that it shows drops in the signal or intermittence • 50% of students rate how to regulate network security
Service variables	• 60% of the students in this cluster do not know the processes that the university is carrying out to improve the technological infrastructure • 62% stated how to regulate their general assessment of the access service to the wireless network of the university campus • 56% of students qualify as regulating the level of satisfaction of WiFi network services. • 56% of the student rated the support services and correction of failures of the management unit and campus systems as regular • Despite the regular qualifications, 96% of the participating students consider that the wireless network service facilitates the execution of activities and academic consultations
Connection times/file download times	• 70% of the students said that, on average, they wait between 0–2 min to connect to the wireless network and access the internet and 20% wait between 3 to 5 min • 52% of the students said that, on average, they must wait between 3–5 min to download a file; of course, this depends on the size of the file
The frequency of use of the University's internet/personal mobile networks	• 72% of students have a high frequency of internet use • 59% of the participants said that they use their mobile phone to access Wi-Fi, due to faults in the campus network

Cluster 2 (C2) is composed of 11 individuals, representing 17.46% of the sample. In this group, students are satisfied with the Internet service of the university campus, which are characterized in general terms, for their satisfaction with some of the aspects evaluated in the survey, specifically in the technical characteristics of the Internet service. They are mostly students of the Industrial Engineering program, who do not have as much level of knowledge as students of related programs with the area of ICTs, 63% of participants use the WiFi network frequently.

As common variables of this cluster, there is the excellent perception that students have about the technical characteristics of the service, such as availability, signal coverage, response times, real-time connection, stability and network security. These services were rated in the excellent range by more than 80%, although they did not think the same regarding speed, in which 54% of the participants rated as slow. Another of the key variables of correspondence in this cluster is related to the ease of the wireless network for the development of its activities and consultations, to which 72% of respondents coincided positively. On the other hand, we identified as grouping variables, the time of connection to the network and time of downloading files from the WiFi network, to which the students responded that the waiting time is high, on average, between 6 and 10 min. Although the general results for this group show a general pattern of satisfaction, it is necessary to bear in mind that the favorable perception may be due to the lack of technical expertise or affinity with the area of knowledge of the ICTs. For this reason, their opinion may be less demanding than that of Cluster 1, where students from the computer and electronic areas are grouped. It is also necessary to generate the work plans and projects needed to improve the speed of the network and the times of connection and download of contents.

On the other hand, the third Cluster (C3) is made up of 2 individuals, corresponding to 3.17% of the sample. In this group, students dissatisfied with the wireless internet service provided by the university are located, who are characterized in general terms, by their total dissatisfaction, specifically in the technical aspects of the WiFi internet service. In this cluster, the academic program does not affect general dissatisfaction, since this group is made up of a student of Industrial Engineering and a student of Technical Professional in Industrial Electronic Maintenance, so it is not conclusive to state that the type of program it is associated with the level of satisfaction in this group. As common variables of this cluster, are the technical characteristics of the service, such as availability, signal coverage, response times, real-time connection, stability and network security, which were rated in the lousiest range in most 80% This raises the need to establish action plans that allow improving the technical aspects in the provision of the internet service. Finally, the independence of the variables within the cluster was analyzed, using the Chi-square test. The dependent or significant variables were those that obtained a p-value lower than the level of significance ($p\text{-value} < 0.05$), as shown in Table 2:

Table 2. Determination of significant or dependent variables, according to chi-square test, software R3.5.0

Code	Description of the variable	P-value	Df
V8.5	How it qualifies the stability of the wireless network (little or no intermittency or signal drop)?	1.394047e−12	8
V8.1	How do you rate availability of the wireless network (WiFi network always available or not available)?	6.256282e−12	8
V8.4	Rate the connection in a real time of several users	9.971297e−12	8
V8.3	How do you rate the response time of the network?	3.012736e−09	8
V5	How do you rate the speed of access or connection to the wireless network?	7.436413e−09	8
V15	What is the general assessment of the wireless network access service of the institution?	2.426083e−07	8
V8.2	How do you rate the coverage of the signal? Is it possible to connect from anywhere on the campus?	2.301501e−06	8
V4	The current level of satisfaction of connection to the network services offered through the Wi-Fi network	5.504881e−05	8
V8.6	How it qualifies the security of the network (it has too many filters, it allows to navigate without so many restrictions)?	8.176920e−05	8
V10	How much time do you expect to connect to the wireless network and access the internet?	3.326749e−03	4
V7	Considers that the current technological infrastructure is capable of: being improved, remaining the same	2.780727e−02	2
V9	Do you consider that the wireless network service facilitates the execution of your activities and educational consultations?	3.235995e−02	2
V12	How often do you have to enable the sharing of your mobile to access the internet because the Wi-Fi network of the institution did not allow it?	3.303245e−02	6
V1	Academic program	4.267513e−02	6

In this sense, 14 of the 18 variables in this study were significant or dependent; that is, they are variables with influence on the formation of the clusters or grouping of individuals. Among the significant variables, variables related both to the technical characteristics of the wireless internet connection and attributes of the service and the attention of personnel in the area of systems and technology were found. The academic program was also perceived as a significant variable, which affects not only the level of satisfaction of the users but also the quality of the answers provided by the students, taking into account their affinity or expertise in information technologies and communications. These results allow us to conclude that the variables identified are relevant in the evaluation of Internet service satisfaction by university users and that, through these variables, groups of variables and observations can be identified and characterized and focused. Jointly or multivariate, strategies to improve user satisfaction within the university campus.

5 Conclusions and Future Works

A wireless network optimization process starts from the fact of having a design and implementation of a wireless network infrastructure under international standards. It is necessary to perform an analysis of the state of the wireless network, verify if the design is following the regulations if its implementation has taken into consideration a series of requirements and protocols necessary for its operation. In the present research work, variables such as bandwidth use, network availability, throughput, latency, among others, were analyzed to verify the current status of the institution's wireless network. This analysis applies to any entity.

SDN is an innovative approach in the local environment for the optimization of both wired and wireless networks. Although in the world there are several studies and implementations regarding the subject, in Colombia and especially in our city Barranquilla, little has been investigated and executed. SDN allows organizations to grow in their technological infrastructure, optimizing the behavior of the internal network, in a centralized, scalable and reliable way. Due to costs, it is not possible to acquire equipment that supports SDN, however, a tool such as Mininet is used to simulate the performance of a wireless network configured with SDN, very adjusted to the reality of educational institutions, in order to take the measurements of the variables, and support a change in the infrastructure. The versatility of Mininet allows it to be used in a multibrand environment such as the one we have in the Institution (and in large part of these in the city), where we have equipment from different manufacturers. The SDN optimization approach that is to be studied and proposed for the optimization of the wireless infrastructure allows new means for network virtualization and programmability, which facilitate how networks can be designed and operated, including the defined characteristics by the user and the personalized behavior, even at runtime.

The present project has two important statistical instruments, from which the results of the second instrument have been shown. The first will be to define a mathematical criterion or algorithm that allows maximizing the level of satisfaction of the users of the network, which helps to validate that the process of optimization of the wireless infrastructure is of impact for the academic community. The second statistical component of the research is a survey, a fundamental tool to measure the success of the project, whose results were shown and discussed previously.

Future works based on the project include completing the mathematical criterion or algorithm to maximize the level of user satisfaction, simulating a functional topology of the SDN wireless network infrastructure with Mininet and presenting the results before the institutional directives, for motivating them to change the current network infrastructure. These results can be replicated in other institutions, considering the factors of each entity.

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