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Efficiency Optimization Model for 802.11ac WLAN Networks

Héctor Manuel Herrera Herrera[1], Octavio José Salcedo Parra[1, 2], Danilo Alfonso López Sarmiento[1]

[1]*Faculty of Engineering - Universidad Distrital Francisco José de Caldas, Bogotá D.C., Colombia.*

[2]*Faculty of Engineering - Universidad Nacional de Colombia, Bogotá D.C., Colombia*.

Abstract

In this article, the existing models used to optimize the efficiency of wireless networks with the 802.11ac communication protocol are assessed. Two of the efficiency optimization models are analyzed: one is based on Markov chains and the other is based on the ant colony algorithm. Their purpose is to improve the efficiency and reliability of 802.11ac wireless networks. The characteristics, contributions and improvements of each model are described as well as comparing which model is more effective in terms of improving the performance of the targeted networks. Afterwards, a model is proposed to optimize the efficiency of WLAN networks with 802.11ac technology, focusing on hardware use (access points or APs) which implies carrying out an analysis and assessment through the model and make the required adjustments. This information can be used by managers and designers to verify and use the proposed model to improve the efficiency of 802.11ac wireless networks. Finally, the proposed model is tested with a real wireless network at the Universidad Distrital Francisco José de Caldas. The topology has three access points in order to guarantee the coverage for wireless internet in the Suarez Copete building. The access points are properly interpolated in order to apply the model, which leads to a satisfying optimization result. The number of APs is minimized, and the use of the radio-electric spectrum is optimized.

Keywords: 802.11ac, AP, Efficiency, WLAN.

INTRODUCTIÓN

A common problem for people who have domestic plants such as flowers, bulbous plants garden, aromatic plants and indoor plants, is to be sure when they have received the right amount of water. Through an irrigation system, it is possible to save the amount of water used in this task, since it goes to the floor with a specific volume. To provide a solution to this problem is to design a device with a sensor of humidity in the soil, connected to an Arduino Board, which shall contain information on irrigation (carnations, tulips and daisies) flowers and ornamental plants (ticket, Aloe, cactus), to activate the automatic irrigation by means of a solenoid valve and notify by email to the user the need to supply water for irrigation.

BACKGROUND

With the increasing use of wireless networks (WLAN) compliant with the 802.11 standard. Some problems have risen in the analysis and evaluation tasks to guarantee a good Quality of Service (QoS) to users such as: performance, efficiency and reliability in data transmission due to the high demand in network infrastructure for 802.11 networks. Therefore, there is a need to optimize the limited resources (bandwidth, infrastructure, radio-electric spectrum) which can deliver more efficient design in networks. Problems in WLAN networks areas are related to connectivity (at the instant of time when the user requests to be connected), coverage and stability. The solution of these problems is crucial for network performance that needs to be optimized. Over recent years, wireless networks Mathematical Programming has been used to design wireless networks specially those who require sensors as seen in [4], where the wireless networks combines distance and connectivity with harmony search algorithms and local search methods. This combination results in considerable exactitudes which exceed previous studies on evolution strategies and stochastic processes for network optimization. Wireless local area networks have also been studied to improve quality of service of multimedia calls [5], where are harder to control. In this case, two functions have been minimized with mathematical programming in networks: the probability of a new block call. The results delivered a model capable of reducing the drop probability of a call as well as increasing the efficiency of bandwidth use.

The quality of service (QoS) goes in hand with the development of optimization models in WLAN networks using multi-target programming as seen in [5]. A routing algorithm is used to offer a better QoS in the transmission of packets to the user. The research detailed in the doctoral thesis presented by [6] shows a wide overview of using mathematical programming techniques applied to real telecommunications problems where the main contribution focuses on the applicability of the results achieved on WLAN network optimization. On the other hand, it is important to keep in mind that multi-target optimization leads to functions that are expressed in different units and are often in conflict with the others. The set of feasible solutions becomes larger and more complex due to these characteristics that can determine that traditional optimization problems are insufficient or have a high computational demand. Hence, there is an interest on searching for a solution by adopting less complex techniques that guarantee an adequate optimization of resources when testing a model [5].

STUDY OF EFFICIENCY IN WLAN 802.11ac NETWORKS

Wireless LAN networks that comply with the IEEE 802.11ac standard extend the bandwidth of the 20 or 40 MHz channel (used by the standard 802.11n) to 80 or 160 MHz in order to increase the efficiency (within the radio-electric spectrum) and maintain higher transmission speeds. As a consequence, there could be stations that support different bandwidths within a single area. In the 802.11ac standard, all stations who belong to the same set of basic services (BSS) have to operate in the primary channel, which is a common sub-channel of 20 MHz for retro-compatibility purposes. On the other hand, the secondary channels which include 40, 80 or 160 MHz bandwidths are used along with the primary channel to transmit high and ultra-high performance signals to the stations [7] a seen in Fig. 1.

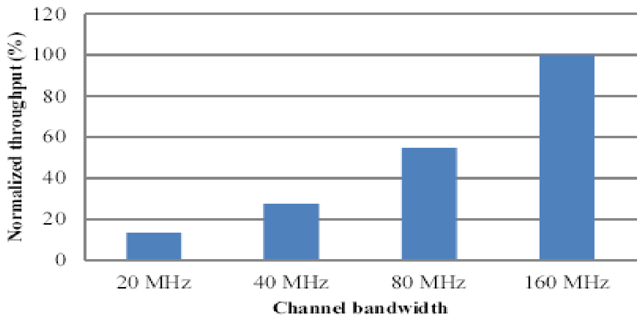

Fig. 1 Comparison of the normalized capacity of the system in the 160 MHz bandwidth (TXOP = 3 mg, number of flows = 8, VTH-MCS = 8). Source [7]

Since some stations that support bandwidth from a different channel in the same BSS (basic service station), some of the frequency resources can be left unused when transmitting signals to stations that can handle narrow bandwidths. For instance, a 20 MHz transmission in a 80 MHz BSS leads to wasting resources at 60 MHz during the transmission which lowers the system's capacity. Another issue with the expansion of bandwidth is that it causes more OBSS (overlapped basic service sets) since the total bandwidth available for WLAN is limited [7]. If some AP (access points) do not use channels effectively and the number OBSS increases, the performance of the system within an area is downgraded [8]. The MU-MC is similar to the orthogonal frequency division multiple access (OFDMA) defined for LTE and WiMAX which programs destinations for each block of resources. In WiMAX and LTE, various sub-carriers are grouped and considered as a block of resources. Our MU-MC scheme assume the conventional channel of 20 MHz WLAN as a unit of frequency resources to maintain compatibility with inherited systems [9] and [10].

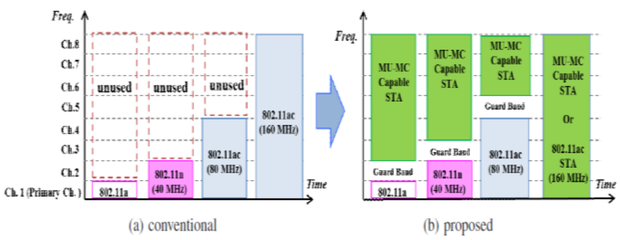

Fig. 2. Use of frequency resources with multiple users in multiple channels (MU-MC). Source: [8]

When data frames are transmitted simultaneously with the MU-MC (multiple user multiple channel) technique, the interference between data frames must be avoided. Under this approach, a conventional channel of MHz is assumed in compliance with the 802.11 ac standard as a basis for a frequency sub-channel. When more than a data frame is transmitted, a protection band of 20 MHz between these two sub-channels is allocated to avoid interference [8], see Fig. 3 (b).

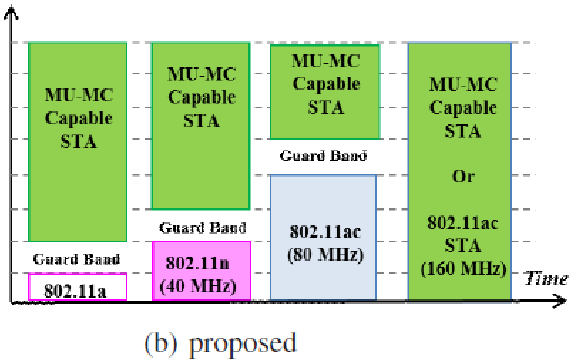

Fig. 3 Proposed model for the MU-MC technique in the 802.11ac standard. Source [8]

The MU-MC method offer a flexible use of the channel and improves the efficiency of the spectrum (See Fig. 4) not only through the use of secondary channels but also with the reduction of the overload of access control based on restraints. In conventional WLAN, a data frame is transmitted to one destination at a time using the CSMA / CA protocol (carrier of the detection multiple access with collision prevention). Under the CSMA / CA protocol, a transmitter terminal must detect the channel during a certain period to confirm that there is no active transmission and wait during a random time before transmitting [11], see Fig. 5. The transmitter terminal needs to repeat the same procedure every time that the transmission begins. In contrast, the MU-MC can send data frames to more than one destination at a time and reduce the overload of the access control mechanism.

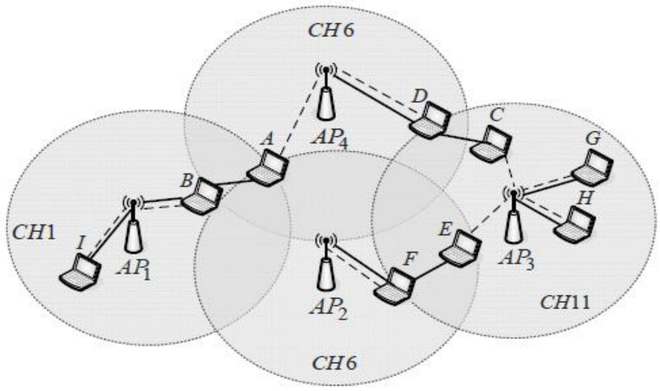

Fig. 4. Improvement of spectral efficiency in 802.11ac networks. Source [9]

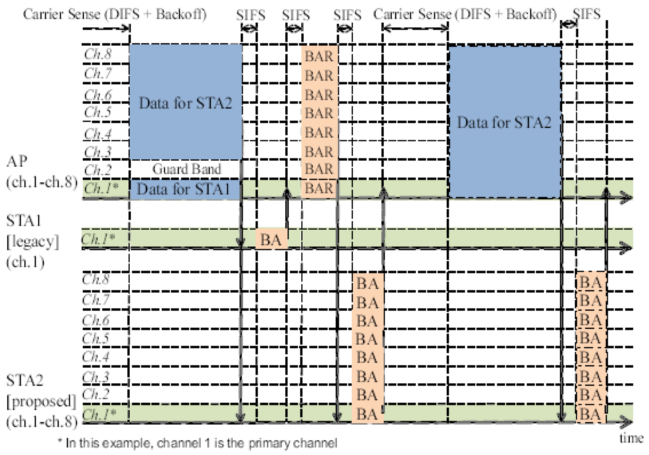

Fig. 5 Method proposed by (Yinghong Ma, 2016) using MU-MC Source: [11]

EFFICIENCY MODEL PROPOSED

The assessment and analysis of WLAN has gained relevance since their growing use has reduced the reliability and efficiency which are paramount in offering adequate QoS to internet users (schools, companies, universities, hospitals). When assessing and analyzing the target function proposed for efficiency in coverage based on the results, local area wireless networks can be optimized with 802.11ac technology with an optimal localization of each access point (AP). Hence, the maximum coverage radius provided by each access point (AP) can be harnessed in order to guarantee coverage in the same area with less APs and analyze subsequently. This offers network designers and managers a mathematical model of efficiency to assess, analyze and optimize performance. Constant assessment and analysis are required to find failures and mitigate them so that users can have adequate service.

The latest advancement in wireless local area networks is the 802.11ac technology, which is proof that wireless connections offer better performance than most wireless connections. The access points of 802.11ac wireless networks available since before the end of 2014 are compatible with data speeds of 433 bps per antenna, leading theoretically to 1.3 Gbps rates with three antennas, exceeding the speeds offered by common Ethernet devices which stand at 100 Mbps [12] [13]. This increase in speed is three times higher than its predecessor 802.11n, achieving higher performance in the use of 802.11ac wireless networks where no cables are needed to connect each operational point (personal desks). The reduction of interference and the efficiency in the use of the radio-electric spectrum optimizes the use of access points through an adequate positioning strategy since it is relevant to reach better performance of the services offered through wireless networks.

Characteristics to consider

The most important characteristics to consider in the development of the efficiency model are the following:

The main characteristics of 802.11ac standard are used to conclude that these types of networks can handle different transmission speeds due to the improved design of access points (APs) that support this technology in order to reduce the loss of packets in the presence of destructive interferences which reduce the power levels of the signal. With the improvement of modulation techniques to protect the signals from noise, the signal's coverage is enhanced [13].

The basic infrastructure of a wireless network is composed of a set of mobile devices (terminals) connected to an access point (AP) which is connected to the wired network with Ethernet technology. An Access Point is basically a device that serves as a wireless bridge for information transmission. Although the theoretical transmission speeds of 802.11ac are often used, various effects contribute to reduce the effective capacity of the standard, the real performance of an 802.11ac cell has transmission rates between 200 and 600 Mbps. Such rates can be reduced if they are connected to large distances or depending on the number of users connected to a single access point.

When there are large distances between the transmitter and the receiver, there will be a deterioration of the efficiency due to the increase in the number of errors in the transmission of BER (bit error rate) packages which requires retransmissions [14] [15] [16]. Modern systems use the widened spectrum configuration to perform discrete jumps thereby improving transmission rates.

The hardware used to design 802.11ac wireless networks intrinsically limits and dictates the transmission rate.

Wireless networks that use 802.11ac technology can include different techniques such as widened spectrum, OFDM, DSSS and Beam forming (instead of producing an uniform emission of the wireless signal, it is directed to the place where the devices are connected. The improvements are evident in terms of coverage, performance and reliability) [17] [18] and make a difference in the performance of 802.11ac wireless networks.

Based on the characteristics mentioned, the efficiency problem to solve in the design and management of WLAN networks lies in the selection of the number of access points and their location within a specific wireless area network that uses 802.11ac technology. Since most designers and managers of wireless networks restrain themselves to installing the lowest possible number of access points and then adding more if necessary, they do not consider the optimization of the efficiency in coverage. However, careful planning assures better performance in hardware use thereby reducing costs.

Mathematical model

The main purpose of the model is to guarantee the coverage within a WLAN network that uses 802.11ac technology, without worrying about possible interference in the access points of a specific area. An integer type model can solve this issue by stating possible locations of APs that enhance the area coverage and optimize the use of the radio-electric spectrum. The parameters included in the mathematical model are:

- The proper location of the access points where users of mobile terminals have access to wireless internet service.

- The number of mobile terminals for each access point, minimizing the number of APs that must be installed in the design of 802.11ac wireless networks.

The interaction of these elements occurs when a mobile station requests a service which is attended by the nearest access point. When the link is established between the mobile station and the access point, the highest transmission speed is then sought while offering quality of service and security. The proposed model for efficiency (coverage) is described:

Number of Access Points in a wireless infrastructure:

$$\boldsymbol{NPA} = Ap_1 + Ap_2 + Ap_3 + Ap_4 + \ldots Ap_n$$

The minimization of the number of Access Points (APs)

$$Minf1(NPA) = \sum_{n \in Ap} Ap_n$$

depends on:

1. $NPA \geq 2$ Number of Access Points to use the model
2. $Ap_n = 1$ indicates that the access point is being used
3. $Ap_n = 0$ indicates that the Access point is available
4. Overlapping percentage between two or more APs ≥ 35%

Table 1. Description of the proposed coverage model

Porcentajedesolaj 35%*NAME*	*TYPE OF VARIABLE*	*DESCRIPTION*
AP	Conjunto	Possible locations of the Access Points (APs)
NPA	Integer	Number of Access Points (APs)
AP_n	Binary	1 if the AP is in use 0 if the AP is available

For instance, if the model were to be implemented in the Suarez Copete building of the Universidad Distrital Francisco José de Caldas, a wireless network is proposed which uses 802.11ac technology with three Access Points (APs) that cover the entire building in the Fig. 6.

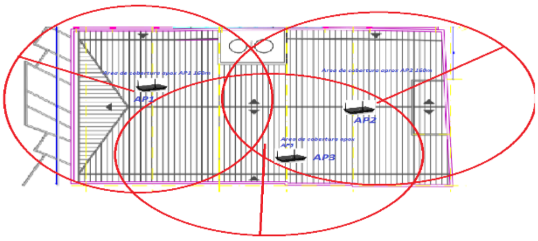

Fig. 6 Plan of the proposed wireless network with 802.11ac technology in the Suarez Copete building of the Universidad Distrital Francisco José de Caldas Source: Author

When using the model, the coverage area of each access point (AP) and overlapping the coverage area between two or more access points. See Fig. s 7, 8 and 9 for the correct application of the model. This intersection area is called the restriction of the model.

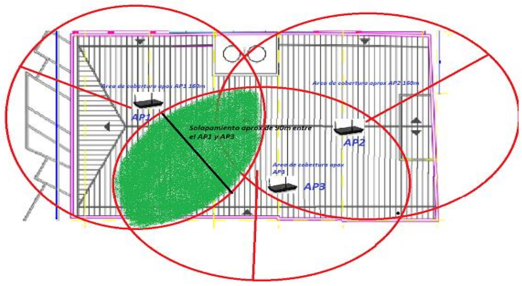

Fig. 7. Interpolation of AP1 y AP3. Source: Author

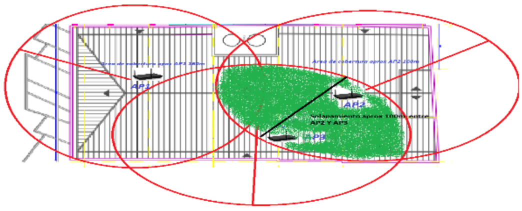

Fig. 8. Interpolation of AP2 and AP3 Source: Author

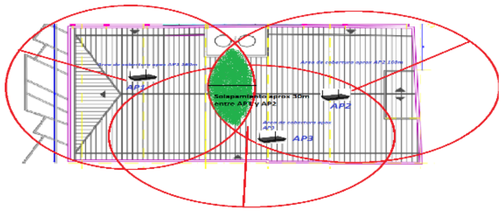

Fig. 9. Interpolation of AP2 and AP3. Source: Author

Restrictions:

- Zone 1 covered by the AP1: Coverage AP1 + AP3 ≥ 1
- Zone 2 covered by the AP2: Coverage AP2 + AP3 ≥ 1
- Zone 3 covered by the AP3:
- Coverage AP1 + AP2 + AP3 ≥ 1

In the restrictions, the interpolations of the Access Points (APs) are described in compliance with 802.11ac technology to cover a specific area. This chapter described the efficiency model and the guidelines are given on its use to optimize a wireless network that operates with 802.11ac technology. Subsequently, the analysis and assessment of the model are carried out.

ANALYSIS AND DISCUSSION OF RESULTS

The efficiency model for 802.11ac wireless networks requires the knowledge of certain elements that allowed the development of said type of model. By synthesizing the model, the two parameters to assess are:

- The location of points of the mobile stations and the potential sites for the installation of access points.

- The maximum number of mobile stations for each access point, trying to use as least as possible in the design process.

The coverage model described in the previous section consists on minimizing the number of access points:

$$Minf1(NPA) = \sum_{n \in Ap} Ap_n$$

which depends on:

$$\sum_{n \in Ap} Ap_n \geq 2$$

The parameters of the efficiency model are stated in Table 2. The simulations were carried out with the LINGO software under the title Verification of the coverage model for three areas of the Distrital university (Suarez Copete building, Fig. 11).

Table 2. Location of the Access points in the study of coverage for the Suarez Copete building of the Distrital university, restricted to the areas that each Access Point (AP) has to cover

Access Points (APs)	*Coverage area*
1	1
2	2
3	1,2,3

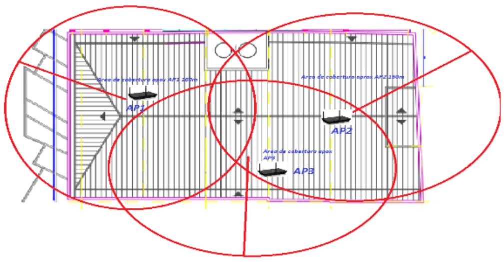

Fig. 10. Proposed distribution of the Access Points for the Suarez Copete Building of the Distrital university. Source: Author

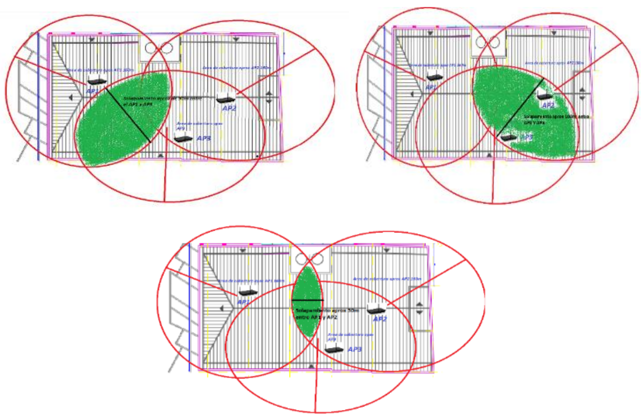

Fig. 11. Interpolation of the Access Points - The areas in green are the restrictions to assess the model in the wireless network. Source: Author.

By introducing this information into the LINGO software (Fig. 12) delivers the efficiency target function which minimizes the number of Access Points to be installed in the three areas for optimal coverage.

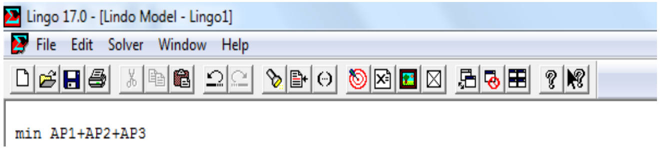

Fig. 12. Optimization model proposed for efficiency (coverage) validated by the LINGO software. Source: Author.

The areas covered by each Access Point must be considered within the model as well as the restrictions (see Fig. 13).

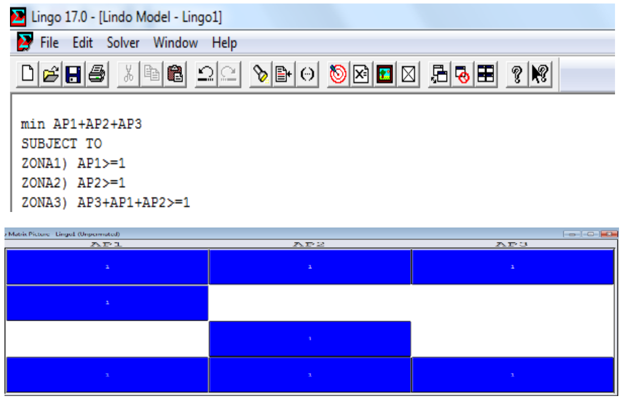

Fig. 13 Restrictions for the location of the Access Points for optimal coverage. Source: Author

The result is a solution model (see Fig. 14) that reveals the efficiency of heuristic algorithms and determines a global and non-local solution.

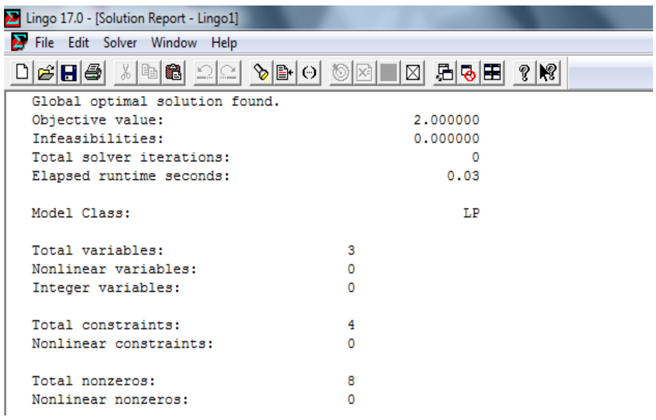

Fig. 14. Solution obtained for the proposed model in the LINGO software for the coverage are of the Suarez Copete building. Source: Author

The validation process reveals that the proposed model optimizes the efficiency of the wireless network 802.11ac and that the number of Access Points (AP) needed to cover the three areas optimally is two. The number of variables (coverage restrictions) used to test the model were three. The optimal locations of the Access Points for proper coverage are shown in Fig. 15.

```
Variable           Value        Reduced Cost
     AP1        1.000000           0.000000
     AP2        1.000000           0.000000
     AP3        0.000000           1.000000

     Row    Slack or Surplus      Dual Price
       1        2.000000          -1.000000
   ZONA1        0.000000          -1.000000
   ZONA2        0.000000          -1.000000
   ZONA3        1.000000           0.000000
```

Fig. 15. Areas where the Access Points (APs) have to be located to guarantee optimal coverage in the three areas of the building. Source: Author

Fig. 16 shows that the optimization model potentiates the number of Access Points with their location. An optimization of the Access Points is obtained going from three to two to cover the same building (Table 3).

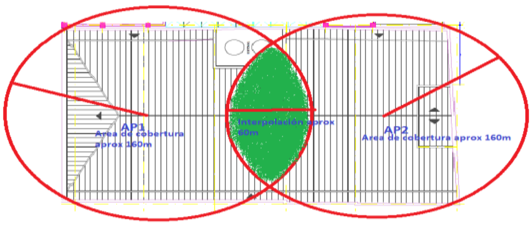

Fig. 16 Optimization result of the proposed model for efficiency (coverage) Source: Author

Table 3. Optimization result using the model for efficiency in coverage

Access Points (APs)	AP1	AP2	AP3
Coverage area for each AP before applying the model	AREA1	AREA2	AREA3
Percentage of coverage for each AP before applying the model	33,30%	33,30%	33,30%
Coverage area for each AP after applying the model	AREA 1 AREA 3	AREA3, AREA2	-------
Percentage of coverage for each AP after applying the model	50%	50%	--------
Optimization percentage of each AP	16,70%	16,70%	--------

The results of the model are optimal when applying to a wireless network with 802.11ac technology since the hardware use is optimized. In this case, the APs are interpolated based on parameters included in the model and they are minimized to boost efficiency (coverage of each AP) by choosing the best locations. In contrast, related articles focus on guaranteeing better bandwidth thereby optimizing the use of radio-electric spectrum without considering that several access points can be overlapped in the same area. This improvement is achieved with the model by assessing the minimum interpolation percentage between two APs and optimizing the efficiency of the wireless network as shown in the comparison stated in Table 4.

Table 4. Comparison of related work with the propose model

Comparison of related work with the proposed model		
Models	Efficiency of the WLAN 802.11ac network	Improvement on the possible location of the AP
Proposed	*16%*	*50%*
Related work	*10%*	*15%*

CONCLUSIONS

It is concluded that following the design considerations and choosing the correct network architectures, the optimization model with an 802.11ac technology offers greater speed, security and scalability than a wired network which validates the proposed model in the defined scenario. The main advantages of WLAN networks are low costs in implementation and the mobility it offers to clients. However, if the benefits of the 802.11ac protocol were to be maximized, then it is recommended to design the network from scratch with said technology. This means that the characteristics of the technology need to be kept in mind such as bandwidth, operation frequency, transfer rates and delays. Therefore, the same services can be assured for those APs that work with older technologies while maintaining an optimal operation.

Finally, the end result is a tool more useful for network designers and manages at the time of implementing enhancements or a new infrastructure in companies, hospitals, schools, universities and other entities. This model can offer efficiency and optimize WLAN networks with 802.11ac technology in order to harness wireless bandwidth and coverage of channels accessed by mobile devices. The following table shows a comparison between wireless communication protocols 802.11ac and 802.11n. The improvements are verified in the parameters and indicate that the 802.11ac technology is better (see Table 5 and Fig. 17).

Table 5. Performance of 802.11n y 802.11ac technologies

Data speed (average)		*Data speed*		*Lower data rates*	
802.11ac	*802.11n*	*802.11ac*	*802.11n*	*802.11ac*	*802.11n*
42%	20%	83%	43%	5%	10%

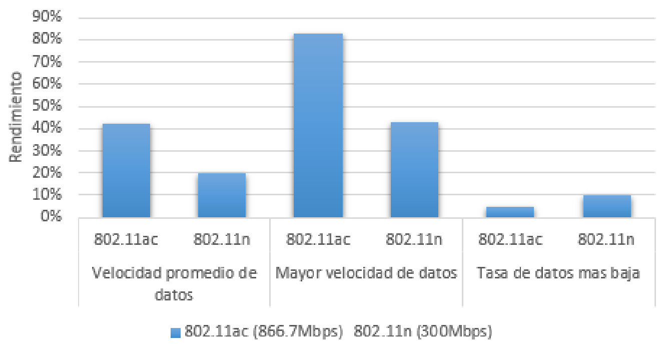

Fig. 17. Performance for 802.11n and 802.11ac technologies. Source: Author

Fig. 16 and Table 3 show the results obtained in terms of improvement after applying the model in wireless networks that operate with 802.11ac technology which minimizes the number of access points and guarantees the expected coverage in the Suarez Copete building.

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