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Performance Analysis in WLAN Networks using 802.11ac Technology

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Abstract

This is to demonstrate that the standard ARDiscovery connection process and the WiFi access point, used by this commercials dron are usable and easily exploitable to the point of disabling the flight by means of a remote attack. In this article, the existing models for the optimization of the performance of wireless networks that use the 802.11ac communication protocol. Two optimization models are analyzed: one is based on Markov chains and the other one uses ant colony algorithms. They seek to improve the efficiency and reliability of wireless networks 802.11ac. The characteristics, contributions and improvements of each model are described. It is also determined which is the most effective method in terms of improving the performance of 802.11 ac wireless networks. Finally, the existing models are assessed to obtain the parameters, techniques and protocols for each model. The access point must be able to recognize these new techinques and protocols at any moment. The web managers and designers can verify the assessed models to improve the efficiency and reliability of wireless networks 802.11ac.

Keywords: 802.11ac IEEE, Efficiency, LAN, Reliability.

INTRODUCTIÓN

The optimization in the design of wireless networks is a crucial matter in diverse fields of knowledge in communications: Applied Mathematics, informatics, tele-traffic Engineering, research and optimization of operations (tasks, activities, assignment of resources, etc.) [1]. These network models offer a useful method to solve real world problems and are widely used in fields such as Telecommunications, Mechatronics, Electronics, electricity, fabrication and logistics.

The use of new approaches in the analysis of networks is also important for the complexity theory, an area that lies in the common intersection of Mathematics and theoretical informatics that handles algorithm analysis [2]. Recent progress on evolutive algorithms focus on solving the practical optimization problems in networks following stochastic algorithms with the strategy based on the search of models, using natural evolutive phenomenon such as genetic inheritance and the fight for survival of the species (Example: Ant colony algorithm [3]).

Hence, the intersection of graph theory and combinatory optimization is the focus at this point. In fact, many optimization problems related to the network design rose directly from the daily practices of Engineering and their operations: finding the shortest path (Dijkstra algorithm) in traffic telecommunication networks, maximum flow, packet loss and route planning problems with specific traffic (data packet), planning connections in traffic networks.

BACKGROUND

Efficiency in 802.11ac WLAN networks

LAN wireless networks that use 802.11ac technology extend the channel's bandwidth from 20 - 40 MHz (used by standard 802.11n) to 80 – 160 MHz to increase the efficiency (coverage) and have greater speeds in data transmission [4]. As a consequence, certain stations could support different channel bandwidths in an area. In 802.11ac specification, all stations are members of the same basic service set (BSS) have to operate in the primary channel which is a common sub-channel of 20 MHz for retro-compatibility purposes. Additionally, secondary channels with bandwidths of 40, 80 or 160 MHz are used along with the primary channel to transmit high (or very high) performance signals to the stations [5] as seen in Figure 1.

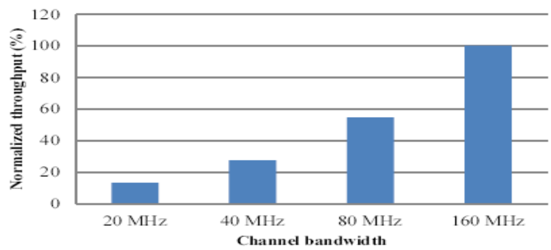


Figure 1. Comparison of the normalized system's capacity for 160 MHz bandwidth (TXOP = 3mg, number of flows = 8, VTH-MCS index = 8). Source: [6]

A problem with the expansion of channel bandwidth is that is causes more OBSS (overlapped basic service sets) since the total frequency bandwidth available for WLAN is limited [6]. If some APs do not use channels effectively and the number of OBSS increases, the performance of the system in an area will also be downgraded [7]. Hence, a Multi-User Multi-Channel (MU-MC) transmission technique is proposed to improve the efficiency of transmissions in the downlink. This technique allows an AP (Access Point) to transmit data threads to different destinies over several sub-channels (Figure 2). In WLAN systems, orthogonal frequency-division multiplexation (OFDM) is a basic transmission technique for 802.11a/n/ac and MU-MC uses flexible sub-channels to improve the efficiency of the spectrum [6]. The MU-MC scheme assumes that the conventional WLAN channel of 20 MHz is a resource unit of frequency to maintain the compatibility of inherited systems [7].

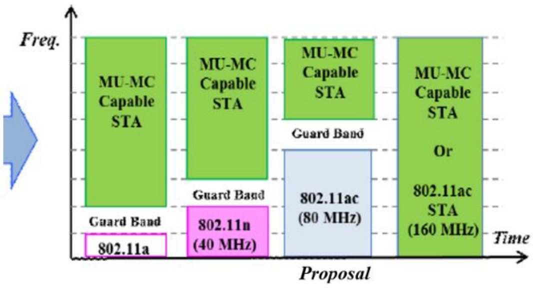


Figure 2. Use of frequency resources with MU-MC (Multi-User Multi-Channel). Source: [6]

Using the MU-MC technique, the flexible use of a channel is enabled and the spectrum's efficiency is improved (Figure 3). Under the CSMA / CA protocol, a transmitter terminal must detect the channel during a specific period to confirm that there is no transmission in course and wait for a random setback time before beginning the transmission [7].

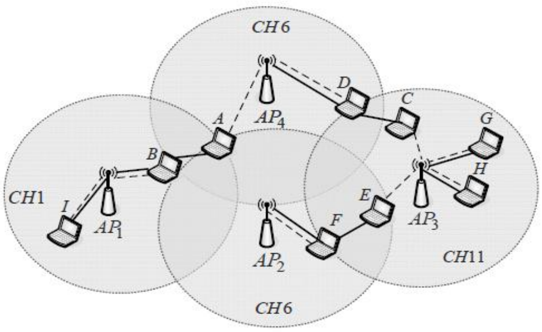


Figure 3. Improvement of spectral efficiency in 802.11ac networks. Source: [7]

Reliability in 802.11ac WLAN networks

Reliability in thread transmission with [8] MU-MC in wireless networks can be analyzed thanks to new techniques and protocols that the AP (Access Point) must be able to recognize at any time. The main techniques are:
Acquire channel information available at every station
Offer protection for the thread sequence using the RTS/CTS exchange (Request send / Delete to send).
The Access Point can acquire information from the sub-channel with the network allocation vector (NAV). If there is more than one destiny, the RTS / CTS exchange is repeated for every destiny with short interframe spaces (SIFS) [6].

Transmission protocol for flow control: The TCP protocol offers reliable data transmission performance but carries transmission delays in packets due to the HOL problem. Additionally, the TCP suffers from large delays in the reestablishment of transmission path after the link disconnections. Specifically, SCTP changes without interruptions the network interface used by the communication endpoint to another network available if the quality of the network is low. There is no disconnection when changing between networks and the quality of the service is maintained for the network communication [9] seen in Figure 4.

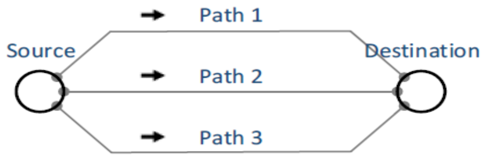


Figure 4. Example: Multiple interface protocol SCTP. Source: [9]

Formal definition of 802.11WLAN performance

In wireless local area networks (WLAN), performance (throughput) can be defined as the amount of information that is transmitted from the emitter to the receptor per time unit without losses in the packets sent [5] and [6]. Performance can be calculated [10], [11], [12] and [13] through a mathematical expression that leads to theoretical results in terms of the established values and situations to determine an approximation of possible results.

The simplest way to define the performance of a WLAN network is to create an ideal scenario where a mobile terminal communicates with an access point (AP) without interference, the channel has no errors and only one AP is active. Only one client station is capable of receiving the packets sent from the AP. The result is a maximum limit [2] to be expected on an experimental environment. By taking this into consideration, the performance is defined as:

$$T = L_p L_p R_d + T_{ccrts}$$

Where:

- L_p = *Packet length in bytes*
- R_p = *Data transmission rate of the wireless network*
- T_{ccrts} =*Control time with RTS.*

The time control with RTS is given by:

$$T_{ccrts} = \frac{cw_{min}}{2} + 4T_{delta} + 4T_{plcpl} + \frac{ACK + CTS + RTS}{R_d}$$

It depends on the parameters related to a WLAN network [2] such as:

- *ACK* = MAC confirmation thread with values of up to 14 bytes.
- cw_{min} = *Minimum contention window with a value of 1213 µs.*
- *CTS = Data within a MAC thread with a value of 14 bytes that indicate that the information is being sent when ready.*
- T_{delta} = *Transmission, reception and processing times with values of 1µ.*
- T_{plcpl} = *Default option for the transmission with a value of 192 µs.*
- *RTS = Data within a MAC thread for the request of packets being sent with a value of 20 bytes.*

The maximum packet size corresponds to the maximum size that an IP packet can take in a wireless local area network. In [14], the same analysis is carried out to obtain the upper limit of the performance in 802.11 networks, leading to the following equation:

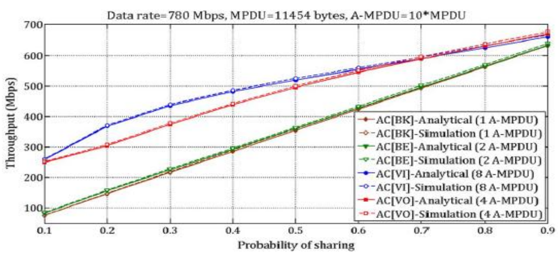
$$T = \frac{\boldsymbol{mPLm + nPLn}}{(\boldsymbol{mTTEm + mTOm}) + (\boldsymbol{nTTEn + nTOn})}$$

This allows an assessment and analysis of the performance in WLAN networks.

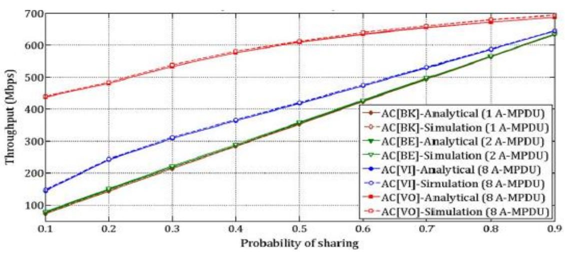
DISCUSSION OF PERFORMANCE MODELS FOR 802.11AC WLAN

A. In the discrete time Markov chain (DTMC) model proposed in [15], an access point is modeled with the 802.11ac communication protocol where the efficiency [16] (coverage of the AP) is improved in the network.

The model assesses and optimizes the performance of the network's traffic, taking as main parameter the use of the XTOP [15] (transmission opportunity) protocol which enables the estimation of the transmission probability therefore improving the efficiency in 802.11ac wireless networks. Figure 5 shows the improvement of the network with the implementation of the model.



(a)



(b)

Figure 5. Optimization of the performance of the wireless network with discrete time Markov chain (DTMC) models in discrete time. Source: [15]

B. The ant colony algorithm (its parameters were described in the previous section) optimizes the performance of wireless networks since it chooses the shortest route (optimal) while verifying that the traffic flow is low to transmit packets without losses. The delays from transmitting on a congested or long route are hence reduced. Figure 6 shows an example of how the ant colony algorithm [3] works. Node 1 is the transmitter and node 11 is the receiver. The characteristics of the assessed models are described in Table 1.

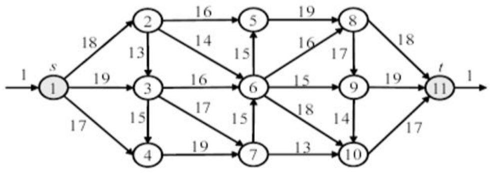


Figure 6. Example of the operation of the ant colony algorithm Source: [16]

Table 1: Characteristics of the assessed models

Model	*Characteristics and mathematical model*
Discrete Time Markov Chain Model (DTMC)	-In this model, the performance of 802.11ac wireless networks is optimized leading to a higher efficiency (coverage of the Access Point AP) and reliability (protocols from specification 802.11ac that improve traffic) of the network. - It improves the efficiency and reliability of wireless networks thanks to the improvement of bandwidths, achieving higher transmission rates and establishing new protocols that optimize the use of the radio-electric spectrum. The Access Point is more efficient and data transmission is more reliable. - This method is based in two-dimensional Markov chains and characterized by delays in the packets in all saturated nodes. *Mathematical Model* $TL(h) = \frac{TXOP(h)}{T_{PHY} + T_{AMPDU} + 2 * SIFS + T_{BA} + 2\delta}$
Ant Colony Algorithm	- Through this algorithm, the shortest path can be found for transmission. It optimizes the performance of 802.11ac wireless networks seeking the least congested route, avoiding losses and delays in data transmission. - It improves the reliability of 802.11 ac wireless networks thanks to new methods that are set in the AP of this new specification. *Mathematical Model* P(h) = ρ + h

Table 1 shows that all the models proposed in [3] and [5], perform an optimization on the performance of 802.11ac networks based on the efficiency (optimal location of the access points) and reliability (protocols used in standards for the improvement of information transmission) of wireless networks. Each model focuses on a target function to carry out the optimization of the variable and improve traffic in 802.11ac networks. Table 2 shows the variables considered for each model to achieve optimization.

Table 2: Variables of the assessed models

Variables	*Markov Chains*	*Ant Colony Algorithm*
T	-	Transmission probability
C	-	Collision probability
$P(h)$	-	Collision-free transmission probability
h	Occupied or unoccupied channel	-
$TL(h)$	Number of AMPDUs of the AC[h] in TXOP[h]	-
$TXOP(h)$	Transmission opportunity in a channel	-
T_{PHY}	Header time in the physical layer	-
T_{AMPDU}	Transmission time in AMPDUs	-
$SIFS$	Short Interframe space	-
δ	Empty slot	-

PROPOSED MODEL

Based on the characteristics shown in 802.11ac wireless networks and the properties of mathematical programming [13], [17], [18] and [19], the optimization model can be expressed as a multi-target function that will allow better harnessing of the network in terms of efficiency and reliability. A wireless network's throughput [20] can be expressed as a problem that needs to:

- Find the best location for the APs in order to maximize coverage and minimizing the number of Access Points installed in a specific area.
- Minimize the delays that occur in the transmission of packets between the APs and the mobile terminals (MT).

Considering that the model must help in the decision making process of network designers and managers, there are some variables that will be used at a certain time, depending on the parameters chosen by the person using the model achieving a degree of flexibility.
The performance optimization model (OptiRendi) that is proposed hereby can be formulated as follows:

$$\boldsymbol{OptiRendi} = \boldsymbol{Cfunc}(\boldsymbol{confiabilidad}) + \boldsymbol{Efunc}\ (\boldsymbol{eficiencia})$$

With: $$\min f1 = \min C \ \sum_{n\in AP}^{N} AP_n$$

$$\min f2 = \min E \sum_{n=1}^{N}\sum_{m=1}^{M} y_{nm}x_{nm}$$

Depending on:

$$\sum_{n \in SC_{em}} AP_n \leq 1 \quad \forall\ em\ \varepsilon\ CEM$$

$$X_n\ \varepsilon\ \{0,1\}\ \forall\ \mathrm{n}\ \varepsilon\ \mathrm{I}$$

$$\sum_{n=1}^{N} x_{nm} \ \leq a_n\ \forall\ n$$

$$\sum_{m=1}^{M} y_{nm} \ \leq c_m\ \forall\ m$$

$$0 \ \leq \ x_{nm} \ \leq \ u_{nm}\ \forall\ (n, m)$$

Finally, the characteristics of the proposed model are described in Table 3.

Table 3: Variables of the proposed model with 802.11actechnology

Name	*Type of variable*	*Description*
AP	Set	Possible locations of the Access Points (APs)
CEM	Integer	Set of possible mobile stations
SC_{em}	Subset of AP	Access Points (APs) that offer services to the mobile terminals
AP_n	Binary	1 if the AP is in use 0 if not
x_{nm}	Integer	Existing flow between nodes n, m
y_{nm}	Integer	Maximum delay assigned to the node n, m
u_{nm}	Integer	Transmission capacity between nodes n, m
a_n	Integer	Maximum number of APs in the area (A)

MODEL SIMULATION IN LINGO SOFTWARE

Table 4: Possible location of the Access Points (APs)

Access Point (AP)	*Areas of coverage*
1	1, 2
2	2, 3
3	3

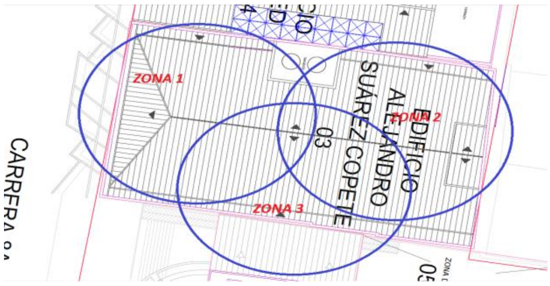


Figure 7. Possible areas with guaranteed coverage in WLAN with 802.11ac technology, in the Suarez Copete building of the Distrital University Source: Authors

By introducing this information into the LINGO software (see Figure 8), the efficiency target function is determined. The number of installed Access Points will be minimized so that optimal coverage can be offered over the three possible areas.

```
min AP1+AP2+AP3
SUBJECT TO
ZONA1) AP1+AP2>=1
ZONA2) AP2+AP3>=1
ZONA3) AP3>=1
```

Figure 8. Proposed optimization model for efficient coverage Source: Authors

The coverage areas must be considered for each Access Point (AP). Those restrictions are put into the proposed model (see Figure 9).

```
SUBJECT TO
ZONA1) AP1+AP2>=1
ZONA2) AP2+AP3>=1
ZONA3) AP3>=1
```

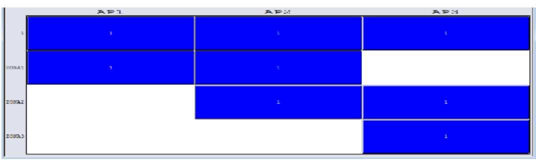


Figure 9. Location restrictions of the Access Points for coverage Source: Authors

This work shows a solution model (see Figure 10) that allows seeing the efficiency of the heuristic algorithms and then determines a global solution, not a local one.

```
Global optimal solution found.
Objective value:                          2.000000
Infeasibilities:                          0.000000
Total solver iterations:                         0
Elapsed runtime seconds:                      0.03

Model Class:                                    LP

Total variables:                  3
Nonlinear variables:              0
Integer variables:                0

Total constraints:                4
Nonlinear constraints:            0

Total nonzeros:                   7
Nonlinear nonzeros:               0
```

Figure 10. Solution of the model obtained in LINGO Source: Authors

The simulation reveals that:

- The model optimizes the efficiency (coverage) of the wireless local area network (WLAN) with 802.11ac technology.
- The number of Access Points (AP) needed to optimally cover the three areas and guarantee good coverage is in fact two.
- The number of variables used to verify the model was three.

The optimal location of the Access Points to guarantee good coverage is seen in Figure 11.

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

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

Figure 11. Areas where the access points must be located to guarantee optimal coverage Source: Author

Figure 12 shows that using the model, the use of APs is optimized having an optimal location for them.

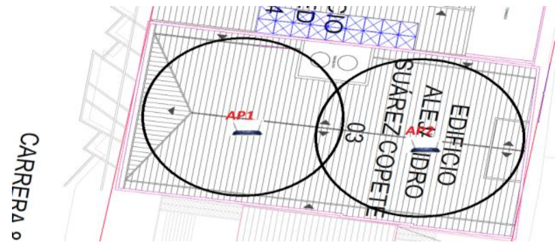


Figure 12. Optimization results of the proposed model for efficiency (coverage) Source: Authors

The optimization, given by the proposed model, impacts the use of the Access Points going from three to two AP for the coverage of the three same areas. The Suarez Copete building is divided into three areas as seen in Figure 7.

DISCUSSION OF RESULTS

The proposed models in [3] and [5] reveal that their solutions to determine the network throughput using genetic algorithms (ant colony method) and Markov chains offer satisfying results.

The solution given by the target function is feasible and the results can be assessed and analyzed regarding the WLAN's performance.

By using the model described in this article to optimize the performance of networks with 802.11ac technology, it can be concluded that two target functions lead to a better model to analyze throughput of wireless local area networks. The proposed functions were efficiency and reliability (joining al the target functions of the models analyzed). The target function efficiency corresponds to the analysis of the coverage of one Access Point (AP) considering the optimal location wherever the AP is implemented. This resource is optimized to the maximum for the offer of mobile internet service in a specific area (design or user needs in Figure 11). The flow of packets [21] is also improved (target function reliability).

The performance of wireless local area networks with 802.11ac technology is assessed, analyzed and optimized. The model is described in detail and verified with the LINGO software on a specific area (Suarez Copete building). In Figure 6, three access points are required to guarantee the internet service over the entire area. The optimization through the LINGO software leads to an optimal location of the Access Points and only requires two of them to guarantee the coverage of the same area.

Through the statistical analysis of the model's optimization, it can be inferred that the Access Points covered 33.3% of the total coverage area while offering internet service. After applying the model, each AP would cover 50% of the area so the optimization of each AP is at 16.7% with optimal location (improved coverage) based on the restrictions of the tests, see Table 5.

Table 5: Percentual data obtained after applying the model

Access Points (AP)	*AP1*	*AP2*	*AP3*
Coverage area for each AP without model	*Zone1*	*Zone2*	*Zone3*
Coverage area for each AP without model (%)	*33,30%*	*33,30%*	*33,30%*
Coverage area for each AP after applying the model	-	*Zone1, Zone2*	*Zone2, Zone3*
Coverage area for each AP after applying the model (%)	-	*50%*	*50%*
Optimization (%)	-	*16,70%*	*16,70%*

CONCLUSIONS

The staggering increase in the use of WLAN networks has created a need for tools that can optimize, analyze and assess the performance of technologies (802.11ac in this case) that offer these type of services. Hence, a model details the most important characteristics of 802.11ac wireless networks in terms of the performance that the specification can bring to the design, management and implementation of an infrastructure with this technology. The proposed model involves multi-target mathematical programming which uses two target functions to analyze and assess in detail the performance of 802.11ac WLAN compared to previous sections of the work that only use one target function (ant colony algorithm - target function reliability and Markov chains - target function efficiency) to study the network throughput.

These target functions of the model resulted from the combination between the previously mentioned models. The first target function – efficiency focuses on the coverage, i.e. the optimal location of the Access Points while the second target function – reliability involves protocols that improve data transmission and minimize its delays. This leads to an optimal solution from the point of view: network and user. A mathematical model is presented that can determine the expected performance of a wireless network with 802.11ac technology through a holistic analysis. The decision maker can determine which benefits (target functions) should be maintained so that they can be prioritized depending on the function to be optimized.

Finally, the result is a tool for network designers and managers when improvements or new infrastructures are implemented in companies, hospitals, schools, universities, etc. The focus lies on the efficiency and reliability models of packet transmission as well as the optimization of the scarce wireless bandwidth. Thus, the equity is increased for mobile devices in access channels (AC). Figure 13 and Table 6 show the improvement of the 802.11ac protocol over its predecessor 802.11n.

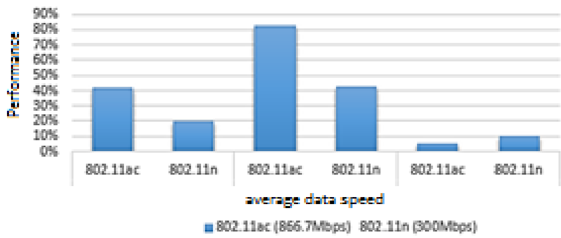


Figure 13. Performance comparison between specifications 802.11ac and 802.11n. Source: Authors

Table 6: Performance comparisons between specifications 802.11ac and 802.11n.

Average data speed		*Average data speed*		*Average data speed*	
802.11ac	802.11n	802.11ac	802.11n	802.11ac	802.11n
42%	20%	83%	43%	5%	10%

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