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Use of Assignment Models as a Strategy for Channel Optimization in the 5 GHz Band Supported in 802.11ac

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Abstract

Objectives: The growing demand of wireless connectivity supported in the standard 802.11 has brought high levels of interference between the adjoining Access Points (APs), due to the shared use of the ISM bands, considerably affecting the network performance. The objective of this paper is to propose an optimization model for the allocation of channels in the band of 5 GHz, supported in the use of allocation models. **Methods Analysis:** A scenario formed by 6-storey building and 24 Access Points distributed within the building (AP) is proposed. The optimization model for the allocation of band frequencies of 5 GHz is represented as a problem of linear programming, based on an allocation model, which is an alternative for the transport. The model seeks to maximize the allocated bandwidth to each AP, to minimize the interference between AP, increase the SINR levels and spectral efficiency, by means of the optimal clustering of channels within the UNII range. In order to determine if the proposed model (MF) does a better allocation of channels than the current model (MA), which incorporates RRM policies? A hypothesis contrast was carried out under difference of means for two independent samples, by means of the use of T-students test. **Findings:** Even though several works have been done related to the channel allocation, there was no evidence of any optimization model oriented to the band of 5 GHz and that is why the proposed model could be considered as the first optimization model for this frequency band. Based on the obtained results, it was possible to observe that the proposed optimization model (MF) did a better allocation of spectral resources compared to the current model (MA), being able to increase in more than 50% in the average SINR with a 95% confidence. **Application:** The model MF can be considered as a tool in future works of research, related to the design and analysis of wireless networks that use 5 GHz bands, in order to assess the performance, efficiency and QOS aspects.

Keywords: Cannel Allocation, Efficiency, Optimization, Performance, SINR, WLAN

1. Introduction

In the last years, the demand for wireless networks by the users has increased due to the mobility and low-cost implementation benefits. Within the range of wireless networks, it is possible to find the network called WLAN (Wireless Local Area Network), which have been used in common places such as homes, offices, schools among others. This type of networks is mainly formed by the use of aggregating devices named Access Point (AP), which allow users to connect wirelessly to the network, having the same function as a switch on a wired network. However, despite that the AP allows establishing wireless connections, the distance to which the AP user should be is rather reduced (inferior to 100 m), due to the power of transmission signal and the obstacles that such signal can

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find in the surrounding areas to reach a user[1]. That is the reason why proliferation of AP is larger with time as the need of the user to have a wireless connection is increasing.

The growth in the AP in WLAN networks has begun to reveal both the positive and the negative effects and the existing deficiencies in the IEEE 802.11 standard. One of the main factors of success in WLAN networks is the use of free bands, which is at the same time, one of the main inconvenient facts, due to the fact that these frequencies are access-free and of shared use among different users, devices and wireless technologies such as Bluetooth, ZigBee, Zwave and even Wi-Fi (Wireless Fidelity), considerably affecting the network performance, due to interference factors and to the inefficient management of the electromagnetic spectrum[2]. Additionally, due to the increase of the AP density in WLAN network, problems related to the performance of such networks have been found. Those problems can be taking place because of the lack of policies for users' management on the traffic load in AP, inaccurate selection of frequencies between channels, electromagnetic interferences, among others. Such problems can make AP not being able to adequately serve the traffic volumes required to offer adequate QOS (Quality of Service) levels to the users of this service[3]. In this scenario, the WLAN networks are unable to seize all their potential. Nonetheless, the incorporation of intelligent resource management policies for radio RRM (Radio Resource Management) could be applied in order to minimize the negative interference side effects of and a non-uniform load distribution.

2. Allocation of Frequency Channels in WLAN Networks

Two spectrum frequency bands with no license are available for its use in the IEEE 802.11 WLAN standard: 2,4 GHz ascribed to the ISM (Industrial Scientific Medical) bands and 5 GHz, corresponding to the U-NII (Unlicensed National Information Infrastructure) bands[4]. The number of available channels can vary from a country to another due to the regulations of each in relation to the allocation of the radio-electrical spectrum[5].

Despite those diverse strategies for the allocation of octagonal channels different from the close AP, such strategies have been only focused on the optimization of channels in 2.4 GHz the bands. This is why this paper has considered the optimization model for the allocation of channels in 5 GHz band. Additionally, it is important to have in mind that in the scenarios with a higher AP density, the problem of channel allocation requires a higher complexity due to the fact that the channels are often established a priori by the network managers, causing two or three AP to have to compete for the same portion of spectrum[6]. Facing this situation, two interference conditions can be presented: The first is called "co-channel interference", which is presented when two or more AP make transmission processes in the same channel. The second is called "adjacent channel interference", which happens when two channels are partially overlapped to one another. Depending on the intensity level and the overlapping level, these types of interference can be considered as levels of noise, mainly affecting the network performance[7].

Even though in IEEE WLAN "free" bands of frequency are used, it is mandatory to comply the regulations for the transmission of radio signals and thus limit the level of power in the transmission signal. With this, it is possible to decrease the interference levels that can be caused to another network or communication systems nearby. Before this situation, the protocol IEEE 802.11h is the one in charge of configuring the power levels suggested for each region, making the adapting process of the transmission powers a lot easier[8]. Although, using the mechanism oriented to reducing the power transmitted for each AP can generate results of great usefulness when minimizing the interference levels, such reduction implies a degradation of SINR (Signal-to-Interference-plus-Noise Ratio), which can get to affect the performance of the network if it is not properly done.

3. Optimization for the Allocation of Frequencies

The allocation of channels involves the allocation of a channel in particular for each Access Point, in which the interference levels are meant to be minimized. In view of the above, the following paper considers the development of an optimization model for the allocation of 5 GHz band channels, supported in the use of allocation models, which are an alternative for the transportation models, allowing to identify the fundamental parameters for the interaction of many factors that can influence a great deal in the decreasing of interference between AP, maximizing the throughput levels and improving the spectral efficiency levels and SINR, present on a particular environment[9,10].

Although most of the Access Point can select the cannel automatically, supported in the 802.11h Standard, under RRM policies between adjacent Access Point, in scenarios with a high density of AP, this mechanism could not be as efficient in terms of decreasing interference when it comes to allocating frequencies in an automatic fashion[11]. As with 2.4 GHz band, 5 GHz band conforms the spectrum that has been allocated to carry out transmission processes in wireless networks and that, little by little, has taken hold due to the rising of new standards such as the 802.11n/ac and due to the need for higher transmission rates in the field of wireless networks[12]. Although the amount of channels in the 5 GHz band is bigger than the number of channels in 2.4 GHz band, it is important to count on processes of resource allocation on an optimal fashion[13]. U-NII band (Unlicensed National Information Infrastructure) is part of the spectrum used by the equipment IEEE 802.11a/n/ac, which operates at five frequency rates: UNII-1 [5150 - 5250] MHz, UNII-2 [5250 - 5330] MHz, UNII-2 Extended [5490 - 5710] MHz, UNII-3 [5735 - 5815] MHz and the ISM [5815 - 5835] MHz[14]. Figure 1 shows the distribution of channels available for the WLAN networks in 5 GHz band.

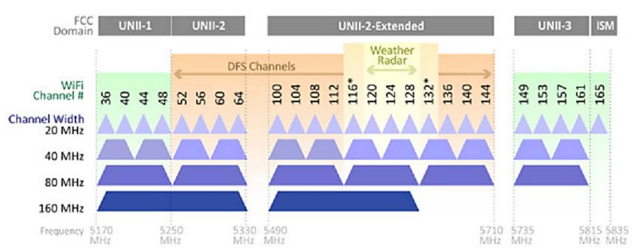

Figure 1. Distribution of channels in 5 GHz band[7].

4. Proposed Model for the Allocation of Frequencies of 5 GHz Bands ($MF_{5\ GHz}$)

For the design of the model of frequency allocations 5 GHz band, the maximization of the bandwidth allocated to each AP has been considered by means of the channels clustering according to the corresponding UNII range, thus minimizing the interference levels. Such minimization is carried out by means of the use of SINR represented as a problem of linear programming based on an allocation model. Table 1 displays a number of channel combinations *i*, the channels coalition, the bandwidth dependent of the specific channel coalition and the differential bandwidth, which will work as a key element to reach optimization processes.

The variable that describes the model are the following:

BW_i^*: Differential Bandwidth allocated to the combination *i* of channels, which is used as differential element within the process of optimization.

BW: Real Bandwidth that is allocated to the combination of channels *i*.

X_i: It is the variable of the model decision. This variable is the one in charge of determining which possible combinations will be the selected according to the environment needs, in order to optimize the allocation of frequency and maximize the available bandwidth for each coalition of channels. The value that can be adopted by the variable of decision is given by:

$$X_i = \begin{cases} 1 \ \text{If the combinationi of channelsis allocated} \\ 0 \ \text{If the combinationi is not allocated} \end{cases}$$

The number of allocated combinations shall be the same as the amount of AP:

$$\sum_{i=1}^{n} X_i = m$$

m: Quantity of AP that will be considered within the process of allocation of frequencies.

n: Number of possible combinations of *N* channels in groups of *m* AP, where:

$$n = \frac{N!}{m!(N-m)!}$$

$$0 \le X_i \le 1$$

According to the information in Table 2, the model proposed for the allocation in the 5 GHz band would be the following model:

Function objective:

$$\max \sum_{i=1}^{n} BW_i^* . X_i$$

Subject to:

$$X_1+X_5+X_7\leq 1$$
$$X_2+X_5+X_7\leq 1$$
$$X_3+X_6+X_7\leq 1$$
$$X_4+X_6+X_7\leq 1$$
$$X_8+X_{12}+X_{14}\leq 1$$
$$X_9+X_{12}+X_{14}\leq 1$$
$$X_{10}+X_{13}+X_{14}\leq 1$$
$$X_{11}+X_{13}+X_{14}\leq 1$$
$$X_{15}+X_{19}+X_{21}\leq 1$$
$$X_{16}+X_{19}+X_{21}\leq 1$$
$$X_{17}+X_{20}+X_{21}\leq 1$$
$$X_{18}+X_{20}+X_{21}\leq 1$$
$$X_{22}+X_{26}+X_{28}\leq 1$$
$$X_{23}+X_{26}+X_{28}\leq 1$$
$$X_{24}+X_{27}+X_{28}\leq 1$$
$$X_{25}+X_{27}+X_{28}\leq 1$$
$$X_{29}+X_{33}+X_{35}\leq 1$$
$$X_{30}+X_{33}+X_{35}\leq 1$$
$$X_{31}+X_{34}+X_{35}\leq 1$$
$$X_{32}+X_{34}+X_{35}\leq 1$$
$$0\leq X\_i\leq 1 \ \forall I = \{1,2,\ldots,n\}$$

The routine developed in MATLAB for the allocation of channels in 5 GHz band, supported in the use of the allocation models is the following:

Routine for the allocation of channels in 5 GHz band

```
% building matrix of combinations between channels for 2.4GHz
1. M = input (‘enter the amount of AP: ‘); % Number of AP
2. V = 1:1:35;
3. C1 = [‘36’; ‘40’; ‘44’; ‘48’; ‘36-40’; ‘44-48’; ‘36-48’];
4. C2 = [‘52’; ‘56’; ‘60’; ‘64’; ‘52-56’; ‘60-64’; ‘52-64’];
5. C3 = [‘100’; ‘104’; ‘108’; ‘112’; ‘100-104’; ‘108-112’;
        ‘100-112’];
6. C4 = [‘132’; ‘136’; ‘140’; ‘144’; ‘132-136’; ‘140-144’;
        ‘132-144’];
7.  C5 = [‘149’; ‘153’; ‘157’; ‘161’; ‘149-153’; ‘157-161’;
        ‘149-161’];
8. C = [C1; C2; C3; C4; C5];
9. Caux = C;

% Building the function Objective starting from the BW matrix for 5 GHz in function of the allocated channel.
10. BWij = [20 21 22 23 50 51 80 24 25 26 27 52 53 81 28
           29 30 31 54 55 82 32 33 34 35 56 57 83 36 37
           38 39 58 59 84];
11. BW = BWij;
12. F = -1000.*BW; % Multiply by -1 to maximize
13. n = 35;
14. lb = zeros([1 n]); % Limits inferior of Xij
15. ub = ones([1 n]); % Límits Superior of Xij

% Matrix of restrictions of equity

% Restrictions for each AP to have only one channels combination
16. for j = 1:35
      Aeq(1,j) = 1;
end
17. beq(1) = m;

% Matrix of restrictions of Inequity
% Restrictions of interference between channels
18. A1 = zeros(20,n); % Auxiliary matrix of restrictions
      with inequity

% Channels UNII-1 36, 40, 44, 48
19. J = 1; % Indicator start of line in auxiliary matrix

% Restriction of interference for channel 36
20. A1(j,1) = 1;
21. A1(j,5) = 1;
22. A1(j,7) = 1;

% Restriction of interference for channel 40
23.  A1(j+1,2) = 1;
24. A1(j+1,5) = 1;
25. A1(j+1,7) = 1;

% Restriction of interference for channel 44
26. A1(j+2,3) = 1;
```

27. A1(j+2,6) = 1;
28. A1(j+2,7) = 1;

% Restriction of interference for channel 48
29. A1(j+3,4) = 1;
30. A1(j+3,6) = 1;
31. A1(j+3,7) = 1;

% Channels UNII-2 52, 56, 60, 64

32. j = 5; % Indicator start of line in auxiliary matrix

% Restriction of interference for channel 52
33. A1(j,8) = 1;
34. A1(j,12) = 1;
35. A1(j,14) = 1;

% Restriction of interference for cannel 56
36. A1(j+1,9) = 1;
37. A1(j+1,12) = 1;
38. A1(j+1,14) = 1;

% Restriction of interference for channel 60
39. A1(j+2,10) = 1;
40. A1(j+2,13) = 1;
41. A1(j+2,14) = 1;

% Restriction of interference for channel 64
42. A1(j+3,11) = 1;
43. A1(j+3,13) = 1;
44. A1(j+3,14) = 1;

% Channels UNII-2 Extended-A 100, 104, 108, 112
45. j=9; % Indicator start of line in auxiliary matrix

% Restriction of interference for channel 100
46. A1(j,15) = 1;
47. A1(j,19) = 1;
48. A1(j,21) = 1;

% Restriction of interference for channel 104
49. A1(j+1,16) = 1;
50. A1(j+1,19) = 1;
51. A1(j+1,21) = 1;

% Restriction of interference for channel 108
51. A1(j+2,17) = 1;
52. A1(j+2,20) = 1;
53. A1(j+2,21) = 1;

% Restriction of interference for channel 112
54. A1(j+3,18) = 1;
55. A1(j+3,20) = 1;
56. A1(j+3,21) = 1;

% Channels UNII-2 Extended-B 132, 136, 140, 144
57. j=13; % Indicator start of line in auxiliary matrix

% Restriction of interference for channel 132
58. A1(j,22) = 1;
59. A1(j,26) = 1;
60. A1(j,28) = 1;

% Restriction of interference for channel 136
61. A1(j+1,23) = 1;
62. A1(j+1,26) = 1;
63. A1(j+1,28) = 1;

% Restriction of interference for channel 140
64. A1(j+2,24) = 1;
65. A1(j+2,27) = 1;
66. A1(j+2,28) = 1;

% Restriction of interference for channel 144
67. A1(j+3,25) = 1;
68. A1(j+3,27) = 1;
69. A1(j+3,28) = 1;

% Channels UNII-3 149, 153, 157, 161
70. j=17; % Indicator Start of line in auxiliary matrix

% Restriction of interference for channel 149

```
71. A1(j,29) = 1;
72. A1(j,33) = 1;
73. A1(j,35) = 1;

% Restriction of interference for channel 153
74. A1(j+1,30) = 1;
75. A1(j+1,33) = 1;
76. A1(j+1,35) = 1;

% Restriction of interference for channel 157
77. A1(j+2,31) = 1;
78. A1(j+2,34) = 1;
79. A1(j+2,35) = 1;

% Restriction of interference for channel 161
80. A1(j+3,32) = 1;
81. A1(j+3,34) = 1;
82. A1(j+3,35) = 1;

83. A = A1; % Addition of restrictions to the matrix of
    inequities

84. for j = 1:20
    b(j) = 1; % Vector of inequity
end

% Resolves the system

85. [x,fval] = linprog( F , A , b , Aeq , beq , lb , ub );
86. R = [v' x];
87. [B,k] = sort(R(:,2),'descend');
88. B = [R(k) B];
89. for I = 1:m
    Channels(i,:) = Caux(B(i,1),:);
  end
90. disp ('The channels suggested are: ');
91. Channels
```

Hereafter, some examples of the results of the proposed model are presented according to the number or AP required:

Results for the case of 4 Access Point

```
Enter the amount of AP: 4
Optimization terminated.
The suggested channels are:

Channels =

149-161 (Channels 149+153+157+161) (BW = 80 MHz)
52-64 (Channels 52+56+60+64) (BW = 80 MHz)
132-144 (Channels 132+136+140+144) (BW = 80 MHz)
100-112 (Channels 100+104+108+112) (BW = 80 MHz)
```

Results for the case of 6 Access Point

```
Enter the amount of AP: 6
Optimization terminated.
The suggested channels are:

Channels =

100-112 (Channels 100+104+108+112) (BW = 80 MHz)
36-48 (Channels 36+40+44+48) (BW = 80 MHz)
52-64 (Channels 52+56+60+64) (BW = 80 MHz)
132-144 (Channels 132+136+140+144) (BW = 80 MHz)
149-153 (Channels 149+153) (BW = 40 MHz)
157-161 (Channels 157+161) (BW = 40 MHz)
```

Results for the case of 8 Access Point

```
Enter the amount of AP: 8
Optimization terminated.
The suggested channels are:

Channels =

52-64 (Channels 52+56+60+64)   (BW = 80 MHz)
100-104 (Channels 100+104)     (BW = 40 MHz)
108-112 (Channels 108+112)     (BW = 40 MHz)
149-153 (Channels 149+153)     (BW = 40 MHz)
157-161 (Channels 157+161)     (BW = 80 MHz)
36-48 (Channels 36+40+44+48)   (BW = 80 MHz)
132-136 (Channels 132+136)     (BW = 40 MHz)
140-144 (Channels 140+144)     (BW = 40 MHz)
```

According to the results obtained for each of the cases, it is possible to observe that an adequate distribution of the available channels has been made according to the number of AP that are part of the network and in coherence with the possible coalitions configured to in 5 GHz band, the ranges UNII and the interference between coalitions equal to ZERO. In view of the above, it is possible to state that the proposed model responds to the processes of optimization in function of the allocation of frequencies, maximizing the bandwidth by coalition and minimizing the interference levels.

In order to estimate the value of SINR, it is necessary to determine the levels of total interference in function of the selected channels. For that, the process goes as follows:

P_{ij} Power in the APi product of the AP_j. For the estimation of the Power of incidence over the AP_i productof the AP_j. For that particular case, the expressions used for the estimation of the values of Power P_{ij}, were obtained empirically supported in the Model Log-Normal Shadowing Path Loss. Thus, P_{ij} is given by[15].

Free space:

$$RSSI(d)[dBm]=P_{ij}(d)=-26,87-26,65Log_{10}(d)$$

With obstacles:

$$RSSI(d)[dBm]=P_{ij}(d)=-41,29-29,07Log_{10}(d)$$

I_{xy}: Interference in the AP_x product of AP_y

$$I_{xy}=P_{xy}.W_{xy}^{ij}$$

$$W_{xy}^{ij}=\begin{cases}1 & si\left|Ch_i-Ch_j\right|=0\\ 0 & si\left|Ch_i-Ch_j\right|\geq 0\end{cases}$$

Where W_{xy}^{ij} is the factor of interference between the AP_x product from AP_y and product of the coalition of allocated channels I and j respectively.

I_x: Total interference over the AP_x

$$I_x=\sum_{j=1}^{k} I_{xy}\,\forall x=\{1,2,\ldots,m\};$$

k: Number of possible sources of interference, product of the m AP that is part of the network over the AP, which is the object of analysis.

$$k=\frac{m!}{2!(m-2)!}$$

The value of $SINR_x$ corresponding to AP_x is given by[16].

$$SINR_x[dB]=10log\left[\frac{P_x}{I_x+N_0}\right]$$

P_i: Power in the AP_x (For practical purposes this power is estimated to 1 m of distance)

N_0: Nivel de ruido de background

Be R_x the rate of data for the AP_x, which, by means of Shannon´s theorem of capacity, is given by[17].

$$R_x=Qlog_2\left(1+SINR_x[dB]\right)$$

Be ES_x the Spectral efficiency for the AP_x, which can be estimated by means of the expression:

$$ES_x=R_x/Q=log_2\left(1+SINR_x[dB]\right)$$

The spectral efficiency in this case also plays an important role in the analysis process when it comes to assessing the quality of optimization processes in 5 GHz band, taking into account that the more its value is, the better the distribution of the resources in the frequency domain will be.

5. Results

5.1 Current State of the Wireless Network– proposed Scenario

In order to perform monitoring campaigns, the software Acrylic Professional Wi-Fi was used. This tool allowed assessing the current conditions of the wireless network in the proposed scenario, which corresponds to a 6-storey building, with Access Point distributed inside it. Such Access Points provide internet services to the student of a school, under policies RRM, in the 5 GHz band. Hereafter, the obtained results are presented in a graphic fashion:

Table 1. Allocation model for 5 GHz band

Band	*i*	*Coalition of channels*	*BW*	BW_i^*
UNII - 1	1	36	20	20
	2	40	20	21
	3	44	20	22
	4	48	20	23
	5	36+40	40	50
	6	44+48	40	51
	7	36+40+44+48	80	80
UNII - 2	8	52	20	24
	9	56	20	25
	10	60	20	26
	11	64	20	27
	12	52+56	40	52
	13	60+64	40	53
	14	52+56+60+64	80	81
UNII - 2 Extended (A)	15	100	20	28
	16	104	20	29
	17	108	20	30
	18	112	20	31
	19	100+104	40	54
	20	108+112	40	55
	21	100+104+108+112	80	82
UNII - 2 Extended (B)	22	132	20	32
	23	136	20	33
	24	140	20	34
	25	144	20	35
	26	132+136	40	56
	27	140+144	40	57
	28	132+136+140+144	80	83
UNII - 3	29	149	20	36
	30	153	20	37
	31	157	20	38
	32	161	20	39
	33	149+153	40	58
	34	157+161	40	59
	35	149+153+157+161	80	84

Table 2. Restrictions of interference among channels

Band	Restriction	Channels	Combinations *i*
UNII - 1	$X_1 + X_5 + X_7 \leq 1$	36	1,5,7
	$X_2 + X_5 + X_7 \leq 1$	40	2,5,7
	$X_3 + X_6 + X_7 \leq 1$	44	3,6,7
	$X_4 + X_6 + X_7 \leq 1$	48	4,6,7
UNII - 2	$X_8 + X_{12} + X_{14} \leq 1$	52	8,12,14
	$X_9 + X_{12} + X_{14} \leq 1$	56	9,12,14
	$X_{10} + X_{13} + X_{14} \leq 1$	60	10,13,14
	$X_{11} + X_{13} + X_{14} \leq 1$	64	11,13,14
UNII - 2 Extended (A)	$X_{15} + X_{19} + X_{21} \leq 1$	100	15,19,21
	$X_{16} + X_{19} + X_{21} \leq 1$	104	16,19,21
	$X_{17} + X_{20} + X_{21} \leq 1$	108	17,20,21
	$X_{18} + X_{20} + X_{21} \leq 1$	112	18,20,21
UNII - 2 Extended (B)	$X_{22} + X_{26} + X_{28} \leq 1$	132	22,26,28
	$X_{23} + X_{26} + X_{28} \leq 1$	136	23,26,28
	$X_{24} + X_{27} + X_{28} \leq 1$	140	24,27,28
	$X_{25} + X_{27} + X_{28} \leq 1$	144	25,27,28
UNII - 3	$X_{29} + X_{33} + X_{35} \leq 1$	149	29,33,35
	$X_{30} + X_{33} + X_{35} \leq 1$	153	30,33,35
	$X_{31} + X_{34} + X_{35} \leq 1$	157	31,34,35
	$X_{32} + X_{34} + X_{35} \leq 1$	161	32,34,35

Figures 2 to 7 show the allocations of channels for each of the SSID configured in the AP, in the 5 GHz band. In such figures, it is possible to observe that there is evidence of high levels of interference between SSID of different AP, due to the fact that most of them are allocated on UNII-1 band. Additionally, policies of configuration in the AP were detected. Those policies suggest that between 3 and 5 SSID have been configured to the same AP, aspect that can have an effect in the performance of AP in terms of processing. Also, apparently for a strategy of the managers to compensate the efficiency losses due to the configuration of more than 3 SSID, in all cases the AP use bandwidth of 80 MHz, that equals the coalition of 4 channels per AP. Such APs are apparently configured in automatic mode. This situation affects even more the performance due to the increase of the interference levels between APs and hence, it decreases the levels of SINR.

Additionally, clear policies for the allocation of channels to the AP are not evidenced. In several cases, it was possible to find that, in more than two adjacent APs, SSID with frequency allocations in the same cannel were presented. This situation generated co-channel interferences, mainly in the middle floors of the building.

Figure 2. Current state building. 1st floor - 5 GHz band.

Figure 3. Current state building. 2nd floor - 5 GHz band.

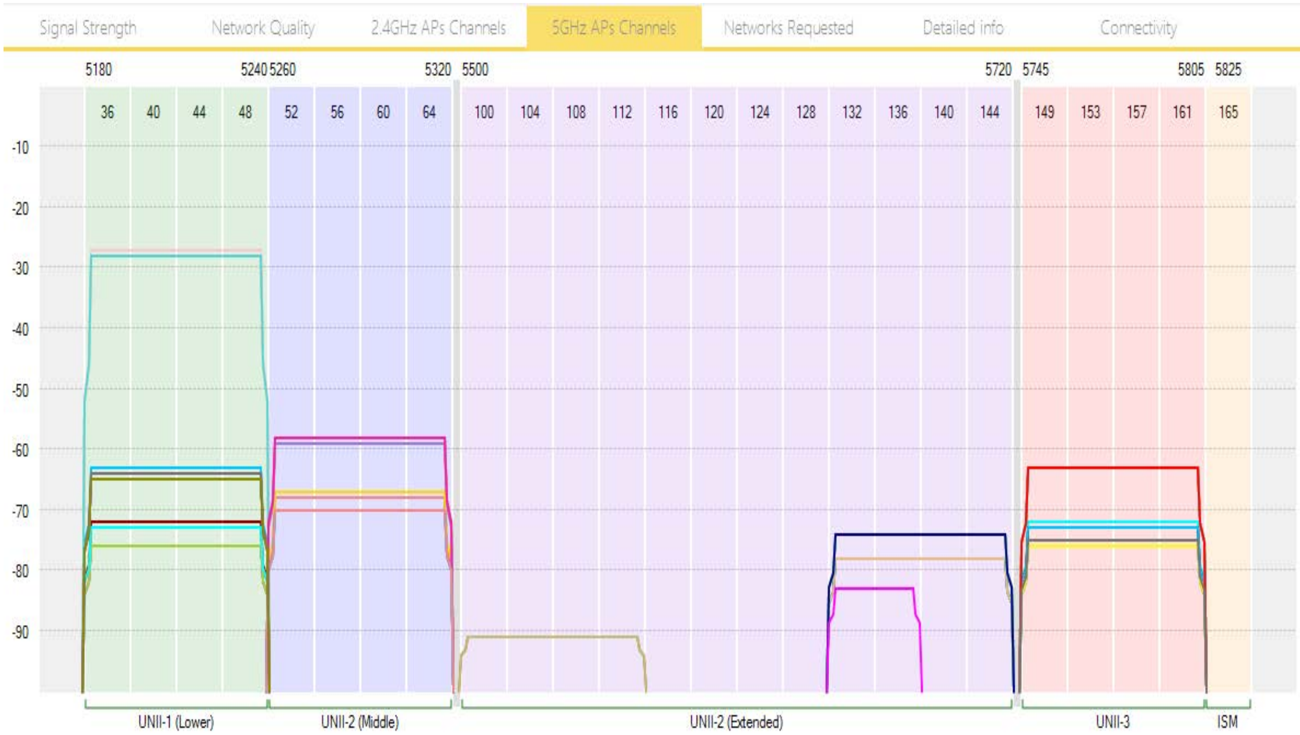

Figure 4. Current state building. 3rd floor - 5 GHz band.

Figure 5. Current state building. 4st floor - 5 GHz band.

Figure 6. Current state building. 5 floor - 5 GHz band.

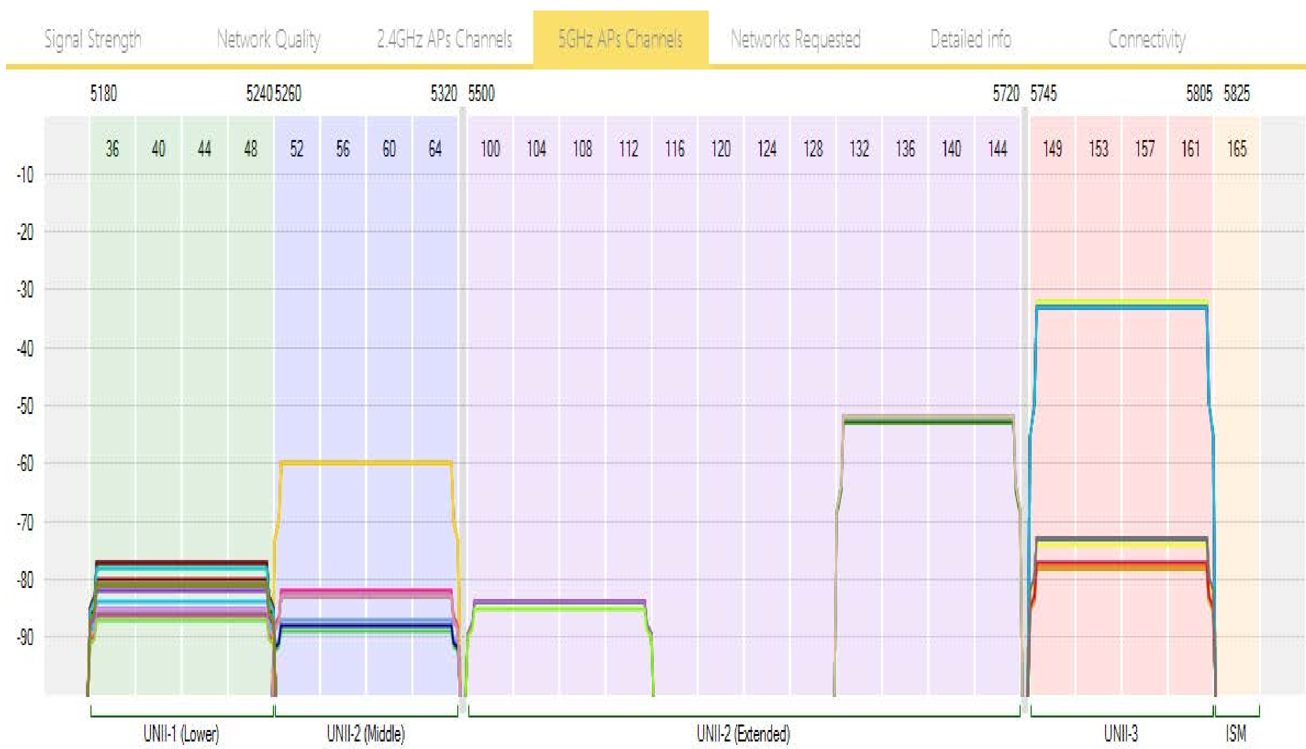

Figure 7. Current state building. 6st floor - 5 GHz band.

5.2 Estimation of Design Parameters – 5 GHz Band

Table 3 shows the estimated values for the coverage ratios, outage probability, coverage area and power of perimeter reception for the 5 GHz band, adjusted to the supported in the Model Log-Normal Shadowing Path Loss[18]

Table 3. Design estimated parameters for the 5 GHz band

Parameters of design	Band 5GHz	
Power of Transmission (P_t) [dBm]	25	25
Type	**Free space**	**Obstacles**
Sensibility (P_{min}) [dBm]	-80	-80
Prob. Of outage estimated (P^*_{cut}) [%]	15	15
Prob. de real outage (P_{cut}) [%]	15,12	15,65
Coverage ratio (r) [m]	53	15
Power of Perimeter Reception $P_r(r)$ [dBm]	-72,74	-74,66
Coverage (C) [%]	93,56	94,18

5.3 Comparative Analysis of the Current Model (MA) vs. Proposed Model (MF)[19]

In order to test the proposed model for the optimization of resources in networks WLAN (MF), a comparative table was made between the current states of the wireless network (MA) and the results estimated by the proposed model (MF). The results obtained are the following:

5.3.1 Current Model (MA) of the Network

Figure 8 shows that for the 5 GHz band, the coverage ratio estimated is that of 15 m according to the propagation model. Two AP is placed on each floor, aligned towards one direction and on the next floor the other direction. The radiation patterns for the higher floor are identified with the color "blue" and those of the lower floor with "red". In view of the above and analyzing what was shown in Figure 8, it is possible to observe that there are some zones, especially in those places opposed to the location of the AP, that do not obtain proper power levels, identified with values below -70 dBm. Before this situation, it is advisable to increase the number of AP per floor and even to perform relocation processes of APs, in order to obtain better coverage conditions. Table 4 shows the results corresponding to the measurement parameters of the spectral conditions of the wireless network in the current model (MA), in which the levels of power of reception, interference over each AP in function of the interference levels generated by the neighbors, SINR values, maximum rate of transmission and spectral efficiency in each AP are registered. In each parameter, it was estimated the average value, the standard deviation, the maximum and minimum value, in order to run tests and statistical analysis comparing with the proposed model (MF).

Table 5 shows the results obtained in the proposed model of optimization, related to the allocation of channels for the AP in the 5 GHz band. Additionally, the coordinates suggested for the relocation of AP under criteria in the new model are presented. In such chart, it is possible to observe that the amount of APs suggested per floor has increased from 2 to 4, in order to improve additionally the levels of coverage of the wireless network. Figure 9 clearly shows that the patterns of radiation for the number of AP suggested by the model are wide and enough to guarantee a great service, by minimizing the zones of signal absence and by offering a total coverage area which is bigger than the one offered in current conditions. This particular situation has a very significant improvement taking into account that, in the case of 5 GHz bands, the ratios of coverage are smaller and it is necessary to guarantee better connectivity conditions in this specific band for the users. Such connectivity allows to reach higher transmission rates and hence a greater performance of the wireless network. Table 6 shows that although the number of AP doubled compared to the current number, the levels of interference decreased and SINR levels mainly improved. Such fact reflected better conditions of spectral efficiency thanks to the optimization model for the proposed allocation of frequencies (MF).

In order to assess if the model of optimization for allocating frequencies and AP coordinates of AP proposed (MF) performs a better job of allocating resources than the method that is currently present in the institution (MA) with RRM policies, the following hypothesis is raised:

5.3.2 Evaluation of the SINR in 5 GHz Band

$$H_o : \mu_{SINR\_5G\_MA} \leq \mu_{SINR\_5G\_MF}$$

$$H_a : \mu_{SINR\_5G\_MA} > \mu_{SINR\_5G\_MF}$$

Where $\mu_{SINR_{5GMA}}$ $y\mu_{SINR_{5GMF}}$ are the media corresponding to the value of current *SINR* and the *SINR* estimated by the model MF, obtained in the 5 GHz band. The hypothesis H_o, states that, when using the model *MF better* levels of *SINR* are obtained, compared to the methodology of current configuration and the establishes the opposite condition.

5.3.3 Evaluation of the Spectral efficiency () in 5 GHz Band

$$H_o : \mu_{\varepsilon\_5G\_MA} \leq \mu_{\varepsilon\_5G\_MF}$$

$$H_a : \mu_{\varepsilon\_5G\_MA} > \mu_{\varepsilon\_5G\_MF}$$

Where $\mu_{\varepsilon\_5G\_MA}$ and $\mu_{\varepsilon\_5G\_MF}$ are the media corresponding to the value of the current spectral efficiency and the one estimated by the MF models respectively, obtained in 5 GHz band. The hypothesis H_o, states that when using the MF model, it is possible to obtain better spectral efficiency compared to the methodology of current configuration and the H_a establishes the opposite condition.

In order to accept or reject the raised hypotheses, it is necessary to raise a contrast hypothesis on the difference of media for two independent samples by means of the t-Student test. For that purpose, the following steps are established:

Table 4. Parameters of spectral efficiency in the current model (MA) – band 5 GHz

		Band 5GHz					
AP i	***Floor***	***Channel***	***$P_r(d_0)$ [dBm]***	***Interf. $I(d_0)$ [dBm]***	***SINR [dB]***	***Max Data rate (R_i) [Mbps]***	***Spectral Efficiency [bps/Hz]***
AP 1	1	36+40+44+48	-34,0	-48,86	14,86	318,99	3,99
AP 1	2	132+136+140+144	-31,0	-72,88	41,88	433,78	5,42
AP 1	3	36+40+44+48	-35,0	-58,75	23,75	370,35	4,63
AP 1	4	36+40+44+48	-33,2	-68,37	35,17	414,14	5,18
AP 1	5	149+153+157+161	-35,0	-66,13	32,12	403,97	5,05
AP 1	6	132+136+140+144	-32,0	-75,95	43,95	439,22	5,49
AP 2	1	36+40+44+48	-30,0	-53,63	23,62	369,74	4,62
AP 2	2	52+56+60+64	-32,0	-66,76	34,76	412,82	5,16
AP 2	3	36+40+44+48	-28,0	-59,05	31,05	400,18	5,00
AP 2	4	149+153+157+161	-32,0	-60,88	28,88	392,09	4,90
AP 2	5	52+56+60+64	-33,0	-69,06	36,06	416,94	5,21
AP 2	6	149+153+157+161	-32,0	-70,49	38,50	424,30	5,30
AP 3	5	36+40+44+48	-35,0	-73,05	38,05	422,98	5,29
Media			**-32,5**	**-64,91**	**32,51**	**401,50**	**5,02**
Minimum			**-35,0**	**-75,95**	**14,86**	**318,99**	**3,99**
Maximum			**-28,0**	**-48,86**	**43,95**	**439,22**	**5,49**
Deviation			**2,1**	**8,12**	**8,13**	**32,73**	**0,41**

Table 5. Coordinates for location and allocation of channels for the AP – proposed model (MF) – band 5 GHz

AP i	***Resulting coordinates***		***Allocated channels***			
	X	***Y***	***Even floors***	***BW [MHz]***	***Odd floors***	***BW [MHz]***
AP1	**10,6**	**23,4**	52+56+60+64	80	157+161	40
AP2	**22,4**	**10,6**	100+104	40	140+144	40
AP3	**33,9**	**23,4**	108+112	40	132+136	40
AP4	**49,4**	**10,6**	149+153	40	36+40+44+48	80

Table 6. Parameters of spectral efficiency in the current model (MF) – band 5 GHz

		Band 5GHz					
AP i	***Floor***	***Channel***	$P_r(d_0)$ ***[dBm]***	***Interf.*** $I(d_0)$ ***[dBm]***	***SINR [dB]***	***Max Data rate*** (R_i) ***[Mbps]***	***Spectral efficiency [bps/Hz]***
AP 1	1	52+56+60+64	-26,87	-76,03	49,16	451,87	5,65
AP 1	2	157+161	-26,87	-76,03	49,16	451,87	5,65
AP 1	3	149+153	-26,87	-85,35	58,47	471,54	5,89
AP 1	4	140+144	-26,87	-85,35	58,47	471,54	5,89
AP 1	5	52+56+60+64	-26,87	-76,03	49,16	451,87	5,65
AP 1	6	157+161	-26,87	-76,03	49,16	451,87	5,65
AP 2	1	100+104	-26,87	-74,22	47,35	447,63	5,60
AP 2	2	36+40+44+48	-26,87	-74,22	47,35	447,63	5,60
AP 2	3	108+112	-26,87	-75,43	48,55	450,47	5,63
AP 2	4	132+136	-26,87	-75,43	48,55	450,47	5,63
AP 2	5	100+104	-26,87	-74,22	47,35	447,63	5,60
AP 2	6	36+40+44+48	-26,87	-74,22	47,35	447,63	5,60
AP 3	1	108+112	-26,87	-74,22	47,35	447,63	5,60
AP 3	2	132+136	-26,87	-74,22	47,35	447,63	5,60
AP 3	3	100+104	-26,87	-75,43	48,55	450,47	5,63
AP 3	4	36+40+44+48	-26,87	-75,43	48,55	450,47	5,63
AP 3	5	108+112	-26,87	-74,22	47,35	447,63	5,60
AP 3	6	132+136	-26,87	-74,22	47,35	447,63	5,60
AP 4	1	149+153	-26,87	-76,03	49,16	451,87	5,65
AP 4	2	140+144	-26,87	-76,03	49,16	451,87	5,65
AP 4	3	52+56+60+64	-26,87	-85,35	58,47	471,54	5,89
AP 4	4	157+161	-26,87	-85,35	58,47	471,54	5,89
AP 4	5	149+153	-26,87	-76,03	49,16	451,87	5,65
AP 4	6	140+144	-26,87	-76,03	49,16	451,87	5,65
Media			**-26,87**	**-76,88**	**50,01**	**453,50**	**5,67**
Minimum			**-26,87**	**-85,35**	**47,35**	**447,63**	**5,60**
Maximum			**-26,87**	**-74,22**	**58,47**	**471,54**	**5,89**
Deviation			**0,00**	**3,94**	**3,94**	**8,43**	**0,11**

Step 1: Estimate the statistical value established for the test by means of the use of the following expression[20].

$$t_{estad} = \frac{\mu_x - \mu_y}{\sqrt{\frac{(n_x-1)S_x^2 + (n_y-1)S_y^2}{n_x+n_y-2}} \cdot \sqrt{\frac{1}{n_x}+\frac{1}{n_y}}}$$

Where:

t_{estad} : Statistical value.

n_x, n_y : Number of samples.

S_x^2, S_y^2: Sample variances in each case.

Step 2: Establish the acceptance range for each of the H_o for $\{t : t < T_{(\alpha;Gl)}\}$ to 5% of significance $(\alpha = 0.05)$, con $Gl = n_x + n_y - 2$ degrees of freedom. To accept H_o, it is neccesary that the statistical (t_{estad}) be located within the acceptance interval established in each case; otherwise, the H_o swill be rejected.

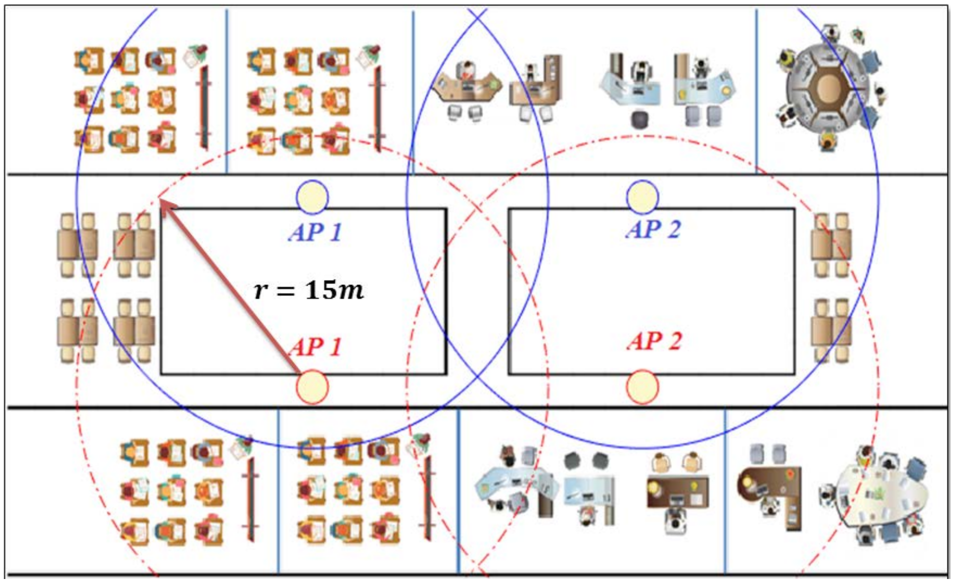

Figure 8. Coverage diagram in the band of 5 GHz – current model (MA).

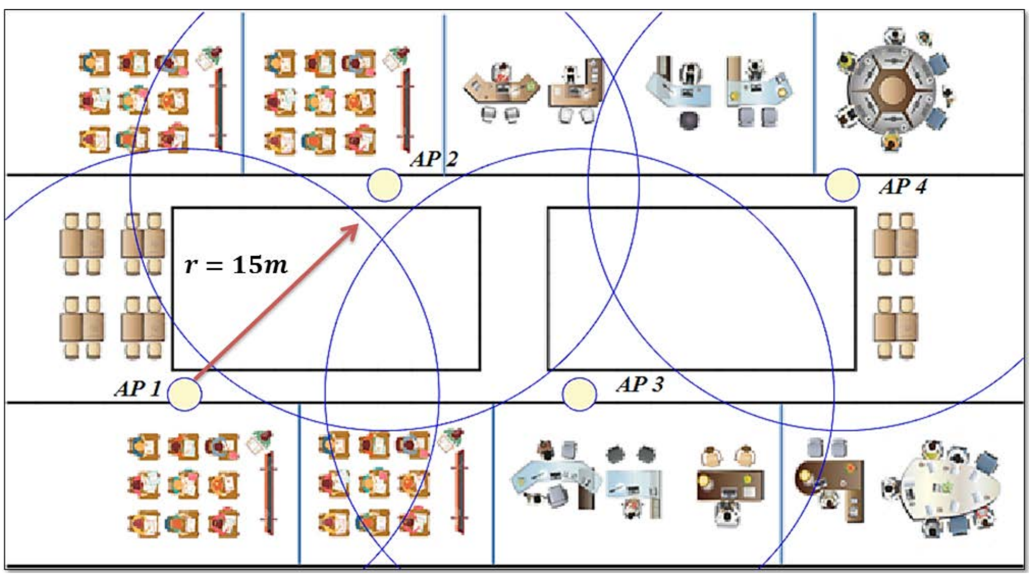

Figure 9. Diagram of coverage in 5 GHz band – proposed model (MF).

Table 7 shows that the value of the test statistic obtained for each established case is found within the acceptance interval. Taking this aspect into account, the H_o is accepted in both cases. According to the obtained results, it is possible to evidence that the model MF performs a better allocation of resources in the spectrum than the ones used for the model MA, having in mind that for the proposed scenario, the model MF allows to reach better SINR levels, as well as a better Spectral efficiency. This aspect will be reflected on a better efficiency in terms of Throughput and delay compared to the current conditions, with a 95% confidence. On the other hand, Table 8 presents a comparative table of the variable SINR, Spectral efficiency and Max Data Rate for the MF and MA models, according to the average value and the difference percentage. $V_{MF}\, y V_{MA}$ Correspond to the value obtained with the model MF and MA, respectively. According to the obtained value, the following aspects can be shown.

- The value of SINR reached by MF exceeds in a 53.83% in the band of 5 GHz compared to the MA model, doubling, in the latter, the SINR

levels with the proposed model compared to the current model. Such aspect improves significantly the transmission and performance of the network and reflects a considerable decrease in the interference levels between APs.
- In the case of Spectral efficiency, it is possible to evidence a significant increase of 12.94% in the 5 GHz band in comparison to the MA model, which is considerably favorable for the voice and video transmission in terms of Throughput y latency
- Finally and product of the last two cases, it is possible to evidence an increase in the maximum rate of transmission or Max Data Rate offered by the model MF of a 12.95% in the 5 GHz band compared to the MA model, thus improving the levels of Throughput, delay and QOS in the network.

6. Conclusions

According to the obtained results during the development of this research, it was possible to demonstrate that the use of the allocation models for the optimization of resources in terms of allocation of frequencies in order to improve the levels of spectral efficiency and network performance, can be considered as a strategy of great importance when it comes to distribute equally the available resources between all nodes part of the network, offering adequate levels of QOS and thus improving significantly the SINR levels and interference in comparison to the current conditions, with a confidence level of 95%. The MF model, allows reaching better SINR levels, Max Data Rate and spectral efficiency compared to the MA model, which is supported in RRM policies, with a 95% confidence; where value for SINR reached by MF overcame in a 53.83% the MA model, duplicating in MF model the levels of SINR. The last aspect improves significantly the processes of transmission and performance of the network and displays a considerable decrease in the levels of interference between APs. In the case of Spectral efficiency, it is possible to evidence a significant increase of 12.94% compared to the MA model, which is quite favorable for the voice and video transmission. Additionally, an increase in the maximum rate of transmission or Max Data Rate was evidenced, offered by the MF model of a 12.95% al model MA, thus improving the levels of Throughput, delay, and QO Sin the network. One of the biggest problems in implementing some of the algorithms related to the optimization of resources in Wireless networks is related to the computational and timing complexity of such processes. Facing this situation, some of

Table 7. Results of t-student test for each hypothesis established

Variable	H_o	Gl	t	Range of acceptance $\{t : t < T_{(\alpha;Gl)}\}$	It is accepted H_o
SINR	$\mu_{SINR\_5G\_MA} \leq \mu_{SINR\_5G\_MF}$	35	-8.864	$(-\infty, 1.690)$	yes
Spectral efficiency	$\mu_{\varepsilon\_5G\_MA} \leq \mu_{\varepsilon\_5G\_MF}$	35	-7.370	$P_r(r)$	yes

Source: Author

Table 8. Comparative table MF vs. MA – band 5 GHz

Variable	Model	Media	% of difference $\%Df = (V_{MF} - V_{MA}) * 100 / V_{MA}$
SINR	MF	50.01	53.83
	MA	32.51	
Spectral efficiency	MF	5.67	12.94
	MA	5.02	
Max Data Rate	MF	453.5	12.95
	MA	401.5	

Source: Author

the researchers have decided to use genetic algorithms and Heuristic methods, among other strategies. However, for the proposed model, optimization mechanisms supported in the allocation models were used. Those models allowed reaching adequate and factual solutions for the proposed scenarios, including low levels of computational and timing complexity thanks to the use of tools such as toolbox of Mat lab. Such tool reduced considerably the computational complexity required to provide a solution to the problem.

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