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Algorithms for Estimation of the Coverage Area and Low Blocking Probability Model Log-Normal Shadowing for 2.4 GHz and 5 GHz in Indoor Environments

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Abstract

Background/Objectives: In designing WLAN networks is difficult to determine exactly the maximum range of the signal radiated by an Access Point, due to the random behavior of the signal received power and receiver sensitivity. The aim of this paper is to develop an algorithm estimate the probability of Court and the coverage area for an Access Point (AP) in the 2.4GHz and 5GHz bands. **Methods/Statistical Analysis:** For estimating the outage probability and the coverage area, two routines in Matlab for each frequency band supported on the propagation model Log-Normal Shadowing Path Loss developed, which allow decompose the received power at an average power and attenuation term shadow. **Topic Relevance:** Although there have been various related design WLANs work, no evidence of an algorithm to estimate the coverage area and the likelihood of court, considering it was found that, in most cases, the estimation of these parameters it is performed graphically and by using software tools on a plane set by the designer. Aspect by which developed in Matlab routines may be used in future research related to the design of WLANs. **Results:** Based on the results it was evident that it is possible to predict the area of coverage and outage probability for the 2.4GHz and 5GHz according to the transmission power, the detection threshold of the receiver, the probability estimated cut and environment characterization between the AP and the receiver, either free space or obstacles, supported using a shadow model attenuation. Additionally, routines allowed the generation of curves describing the behavior of area coverage and outage probability in terms of percent, depending on the radius of coverage, frequency band and environmental conditions, with 95% confidence. **Application/ Improvements:** The developed routines can be used as support tools in future research

Keywords: Coverage Area, Interference, Outage Probability, Reception Power, WLAN Networks

1. Introduction

Due to the continued proliferation of wireless users and access points, it often happens that in one area can reach coexist different wireless networks that are not part of the same delivery system and whose only relationship is not more than the use of a means common (spectrum unlicensed radio) situation creates difficulties when implementing centralized RRM mechanisms[1]. Mechanisms RRM in the field of networks WLAN IEEE 802.11 are intended primarily to reduce problems related to containment and interference, which results in a better Quality of Experience (QoE) as perceived by users, for it RRM should provide efficient mechanisms using algorithms for channel assignment, the type of modulation, power control and load balancing[2]. However, the estima-

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tion of coverage areas and outage probability associated with a cell of radiation generated by an AP not part of the mechanisms of RRM, where in most cases they are set on a priori during the planning by using software tools and estimated graphically[3].

Interest in wireless environments both indoor and outdoor communications, has mushroomed because of the ease of installation, flexibility, scalability, mobility, among others. In the specific case of indoor environments, it is important to predict the behavior of radio propagation of signals due to the phenomena of reflection, diffraction, absorption and scattering, which can significantly affect the coverage and network performance[4,5] models of major spreading are described in the field of WLAN networks through which it is possible to estimate the losses and scope in channel conditions cover when performing a transmission process both in outdoor environments and indoors. Among propagation models are: Lognormal shadowing, Model Log-Distance Model ITU-R Propagation Model COST 231 Keenan and Motley, Model Multi-Wall COST 231, among others.

As IEEE 802.11 networks are widely used, there has been a significant amount of work on the planning of wireless networks IEEE 802.11n[6]. In such networks, the use of transmission scheme Multiple-Input Multiple-Output (MIMO) changes the expected behavior of signal level due to its multiple antenna use, exploiting physical phenomena such as multipath propagation to increase transmission speed and reduce the error rate[7]. In view of the above, this article seeks to establish algorithms to estimate the area coverage and outage probability for the 2.4GHz and 5GHz, depending on the transmission power, the detection threshold of the receiver, estimated outage probability and environment characterization between the AP and the receiver, either free space or obstacles, supported using a shadow model attenuation.

2. Coverage Area and Probability of Court

The problem of design and optimization of wireless networks has been addressed a long time, promoting a large number of investigations. Although there have been several related resource optimization in WLAN networks work, very few studies have considered in their research strategies for optimizing the geographic location of the AP, especially aimed at establishing mechanisms estimation and optimization coverage area and cut the likelihood of wireless networks[8,9].

Attenuation shadow has a great influence on the design process of wireless systems. Due to the random behavior of the received power signal it is difficult to determine exactly the maximum range according to the power sensitivity as the receiver. Given this situation it is necessary to estimate the "Probability of Court" and "Coverage Area", concepts that are vital in the process of wireless network design[10].

2.1 Probability of Court

It is called "outage probability (P_{corte}) " a likelihood that in which the received power *Pr* at a distance d from the transmitter is below the reception threshold *Pmin*.

$$P_{corte}\left(P_{min},d\right)=Prob\left\{P_r\left(d\right)<P_{min}\right\}$$

It is possible to decompose the received power at an average power and attenuation term shadow.

$$P_r\left(d\right)=\overline{P_r}\left(d\right)-\varphi_{dB}$$

Where,

$$P_r\left(d\right)=P_t-L_{dB}\left(d\right) \text{ In logarithmic units}$$

$$\text{Be: } \overline{\Delta P}\left(P_{min},d\right)=\overline{P_r}\left(d\right)-P_{min}\left[dB\right]$$

The outage probability can be written as:

$$P_{corte}\left(P_{min},d\right)=Prob\left\{\varphi_{dB}>\overline{\Delta P}\left(P_{min},d\right)\right\}$$

Giventhenature Log-Normal

$$P_{corte}\left(P_{min},d\right)=Q\left(\frac{\overline{\Delta P}\left(P_{min},d\right)}{\sigma_{\varphi_{dB}}}\right)=Q\left(\frac{\overline{P_r}\left(d\right)-P_{min}}{\sigma_{\varphi_{dB}}}\right)$$

Where is the probability that a variable is greater than Z, ie: $Q(z)N(0,1)$

$$Q\left(z\right)=\int_z^{\infty}\frac{1}{\sqrt{2\pi}}e^{x^2/2}dx=\frac{1}{2}erfc\left(\frac{z}{\sqrt{2}}\right)$$

2.2 Coverage Area

It is called "area coverage" the average percentage of surface which is expected to receive a signal level equal to or greater than the detection threshold. In Figure 1 shows a diagram of the coverage area for a cell in WLANs supported in the shadow model attenuation P_{min}[11].

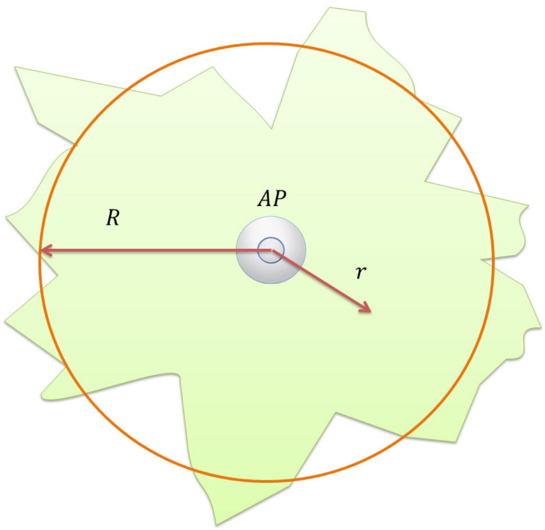

Figure 1. Representation coverage area for a cell in WLANs supported in the shadow model attenuation.

In a model that does not consider attenuation and shadow is considered that the cell radius (supposed loop) equal to the distance at which the average power received $P_r = P_{min}$, the coverage area will be 100%[12]. However, when considering the attenuation shadow, it is necessary to consider the following:

$$1 - P_{corte}(P_{min}, d) = Q\left(\frac{-\overline{\Delta P}(P_{min}, d)}{\sigma_{\varphi_{dB}}}\right)$$

The expression that calculates the coverage area in a wireless network under the log-normal model is as follows:

$$C(P_{min}, R) = \frac{1}{\pi R^2}\int_0^R 2\pi r\left(1 - P_{corte}(P_{min}, r)\right)dr$$

$$C(P_{min}, R) = \frac{2}{R^2}\int_0^R rQ\left(\frac{-\overline{\Delta P}(P_{min}, r)}{\sigma_{\varphi_{dB}}}\right)dr$$

Where it corresponds to the radius of coverage r

Taking into account that:

$$\overline{P_r} = P_t + K - 10log\left[{}^{d}\!/_{d_0}\right]$$

It is possible to express the power margin based on its value in the cell border.

$$\overline{\Delta P}(P_{min}, r) = \overline{\Delta P}(P_{min}, R) - 10.\gamma.log\left[{}^{r}\!/_{R}\right]$$

Replacing in: $\overline{\Delta P}(P_{min}, r)C(P_{min}, R)$

$$C(P_{min}, R) = \frac{2}{R^2}\int_0^R rQ\left(\frac{-\overline{\Delta P}(P_{min}, R) + 10.\gamma.log\left[\frac{r}{R}\right]}{\sigma_{\varphi_{dB}}}\right)dr$$

$$C(P_{min}, R) = \frac{2}{R^2}\int_0^R rQ\left[a + b.ln\left(\frac{r}{R}\right)\right]dr$$

With

$$a = \frac{\overline{\Delta P}(P_{min}, R)}{\sigma_{\varphi_{dB}}} \qquad b = \frac{10.\gamma.\log(e)}{\sigma_{\varphi_{dB}}}$$

The resulting expression to estimate the coverage area is:

$$C(a,b) = Q(a) + e^{\frac{2-2ab}{b^2}}Q\left[\frac{2-ab}{b}\right]$$

In terms of design, for each cell is considered so $P_{min} = \overline{P_r}(R)$ that the margin on the border $\overline{\Delta P}(P_{min}, R)$ is zero, in such case $a = 0$ and the coverage area depend only$b$, which is proportional to $\frac{\gamma}{\sigma\varphi_{dB}}$. Replacing the value of $a = 0$ the above expression, the result is:

$$C_{(b)} = \frac{1}{2} + e^{2/b^2}Q\left(\frac{2}{b}\right)$$

Then, the routine developed in Matlab that allows estimation of radio coverage and outage probability for the 2.4 GHz band is presented, named Prob_Corte24G. It is important to mention that these routines already set the corresponding parameters to model shadow attenuation according to the respective band.

Routine to estimate radio coverage and outage probability for the 2.4 GHz band

```
% Type: Indicator Free / Obstacles Area;
% R: Radio coverage in meters
% Pmin: detection threshold in dBm
% Pt: Tx power in dBm
% PC: Estimated outage probability percentage
% Pcorte: Probability of Royal Court
% C: Percent Coverage Area

Function [R, Pr, Pcorte, C] = Prob_Corte24G (Pt, type, Pmin, PC)

% Initial Conditions iteration
1.  Pcorte = 0;   % Initial Probability
2.  r = 0;        % Initial Distance

3.  while Pcorte<PC
    a. r = r + 1;
    b. if (Type == 1)      % Free space
       gamma = 2216;       % Attenuation factor model (n)
       K = -49.95;         % Factor PL (d0) 2.4GHz band
    Sigma_dB = 5.54;       % Standard deviation
       else                % With Obstacles
       gamma = 3298;       % Attenuation factor model (n)
       K = -48.89;         % Factor PL (d0) 2.4GHz band
    Sigma_dB = 4.67;       % Standard deviation
        end

    c. Pr = Pt + (K-10 * log10 gamma * (r)); % Power received at a distance r

    % Chance ofcutting
    d. Pcorte = 100 * (0.5 * erfc ((Pr-Pmin) / (Sigma_dB * sqrt (2))));

    % Area coverage of a cell to 2.4GHz
    e. a = (Pmin-Pr) / Sigma_dB;
    f. b = 10 * log10 gamma * (exp (1)) / Sigma_dB;
    g. C = 100 * (0.5 * erfc (a / sqrt (2)) + (exp ((2-2 * a * b) / b ^ 2) * 0.5 * erfc ((2-a * b) / (b * sqrt (2)))));

End
```

Additionally, the routine developed in Matlab that allows estimation of radio coverage and outage probability for the 5 GHz band is presented, named Prob_Corte5G. It is important to mention that these routines already set the corresponding parameters to model shadow attenuation according to the respective band.

Routine for estimating radio coverage and outage probability for the band 5GHz

```
% Type: Indicator Free/Obstacles Area;
% R: Radio coverage in meters
% Pmin: detection threshold in dBm
% Pt: Tx power in dBm
% PC: Estimated outage probability percentage
% Pcorte: Probability of Royal Court
% C: Percent Coverage Area

Function [R, Pr, Pcorte, C] = Prob_Corte5G (Pt, type, Pmin, PC)

% Initial Conditions iteration
4.   Pcorte = 0;   % Initial Probability
5.   r = 0;        % Initial Distance

6.   while Pcorte<PC
     h.  r = r + 1;
     i.  if (Type == 1)      % Free space
     gamma = 2.66;           % Attenuation factor model (n)
     K = 51,877;             % Factor PL (d0) 5GHz band
     Sigma_dB = 7.195;       % Standard deviation
         else                % With Obstacles
     gamma = 2907;           % Attenuation factor model (n)
     K = -66.29;             % Factor PL (d0)
     Sigma_dB = 5697;        % Standard deviation
         end

     j.  Pr = Pt + (K-10 * log10 gamma * (r)); % Power received at a distance r

     % Chance ofcutting
     k.  Pcorte = 100 * (0.5 * erfc ((Pr-Pmin) / (Sigma_dB * sqrt (2))));

     % Area coverage of a cell to 5GHz
     l.  a = (Pmin-Pr) / Sigma_dB;
     m.  b = 10 * log10 gamma * (exp (1)) / Sigma_dB;
     n.  C = 100 * (0.5 * erfc (a / sqrt (2)) + (exp ((2-2 * a * b) / b ^ 2) * 0.5 * erfc ((2-a * b) / (b * sqrt (2)))));
     End
End
```

In Figures 2, 3 the curves describing the coverage area for scenarios in free space and environments with obstacles for the 2.4 GHz band and 5 GHz are presented. They can see that the 2.4 GHz band provides coverage areas exceeding the 5 GHz band given the same reference distance. Aspect that is considered of vital importance when making design processes Wireless networks, which will not only estimate radios adequate coverage for each case, but also allow estimating the ranges of signal range in both environments with obstacles and free space to ensure adequate service to each of the user and avoiding the presence of zones of silence that can actually arise at any given moment.

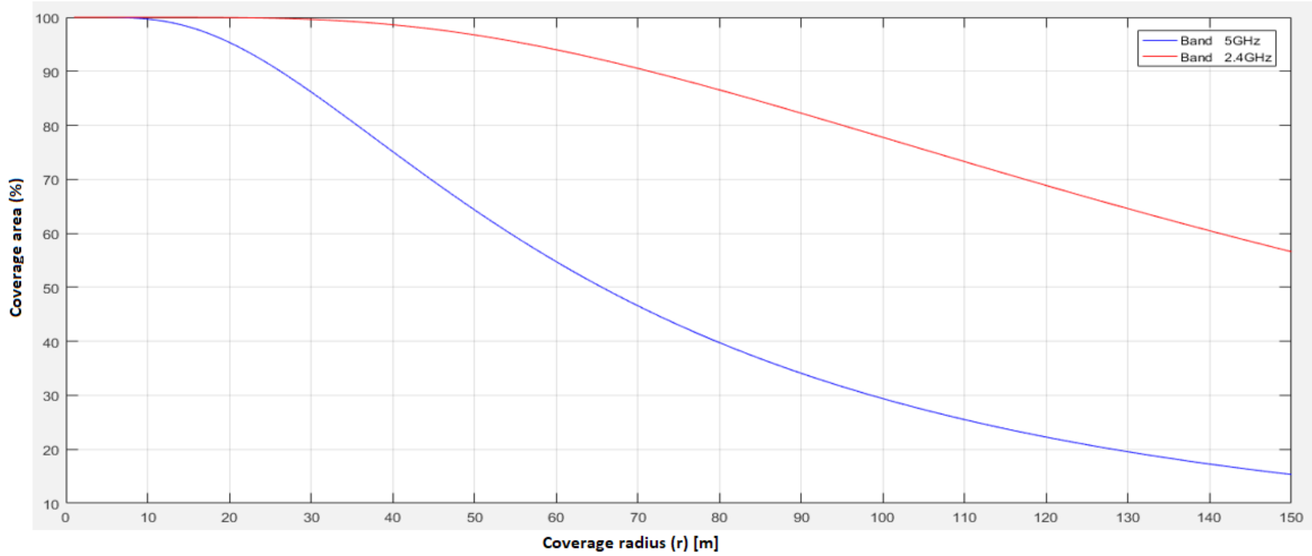

Figure 2. Coverage area in free space based on the frequency band.

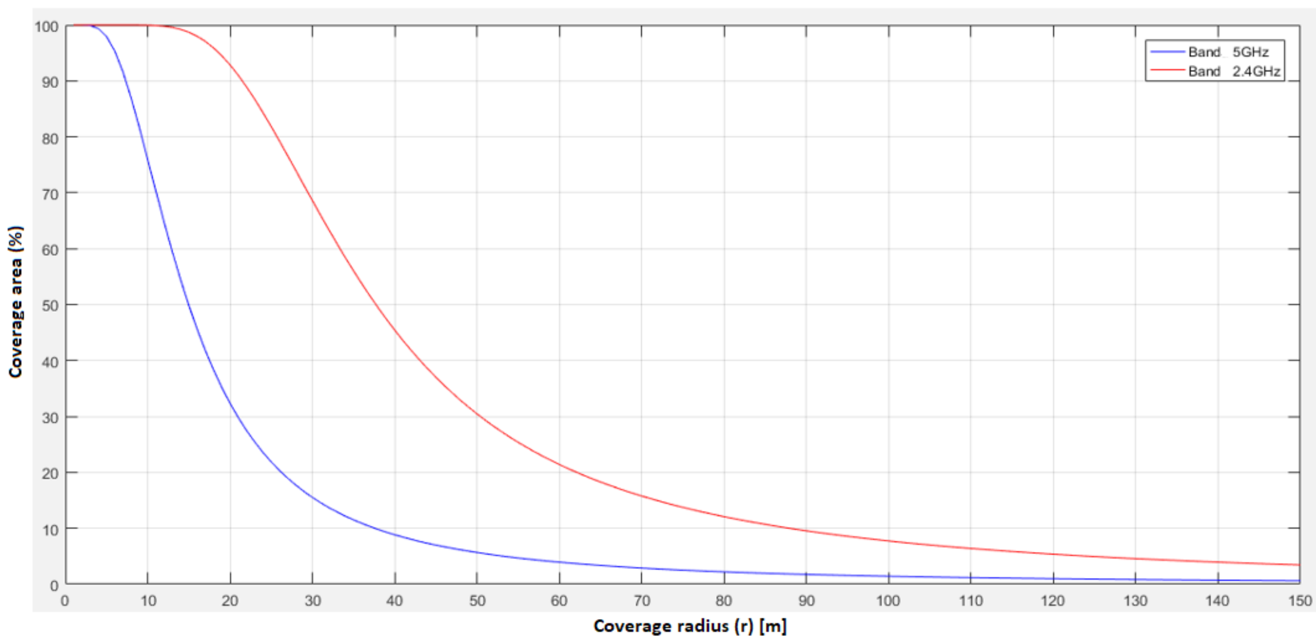

Figure 3. Coverage area in environments with obstacles depending on the frequency band.

In Figures 4, 5 the curves describing the outage probability for scenarios in free space and environments with obstacles based on the 2.4 GHz band and 5 GHz are presented. They can be appreciated that the 5 GHz band offers a probability of above 2.4 GHz band cut given the same reference distance. Aspect that is considered of vital importance when making design processes Wireless networks, which will optimize the design process of wireless networks by identifying more clearly the limits of connectivity between cells, radios adequate coverage for each case in order to ensure adequate service to each user.

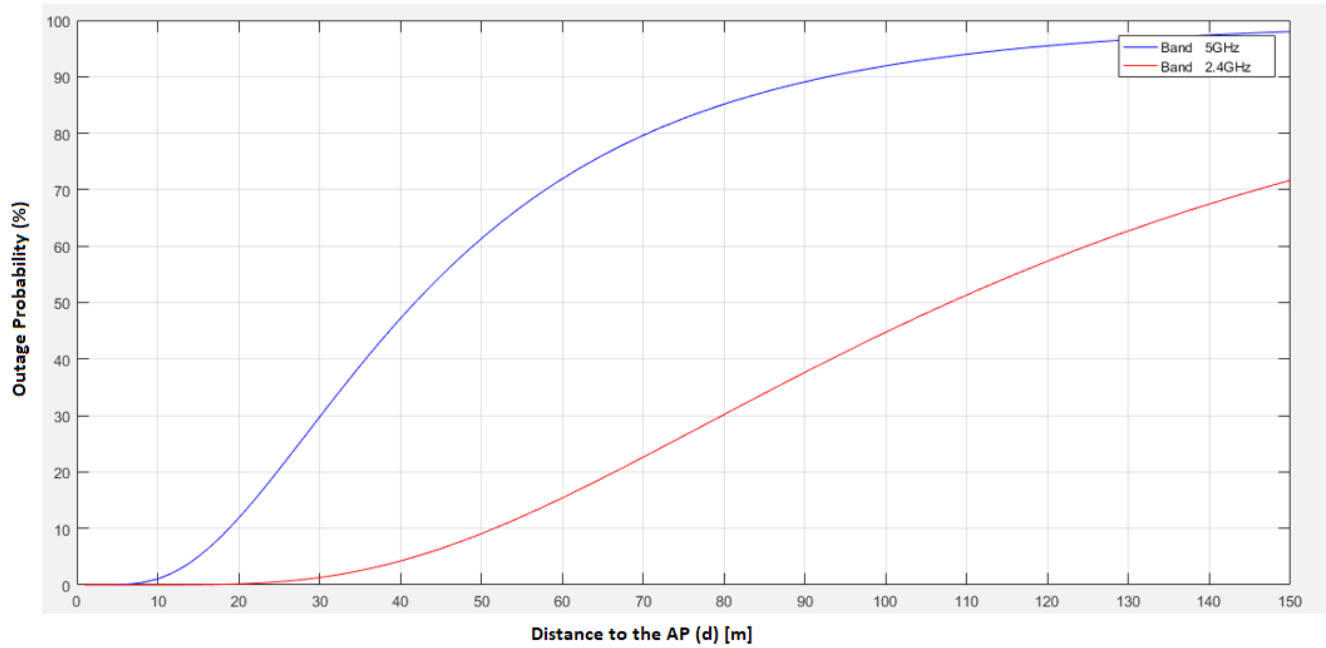

Figure 4. Outage Probability clearance depending on the frequency band.

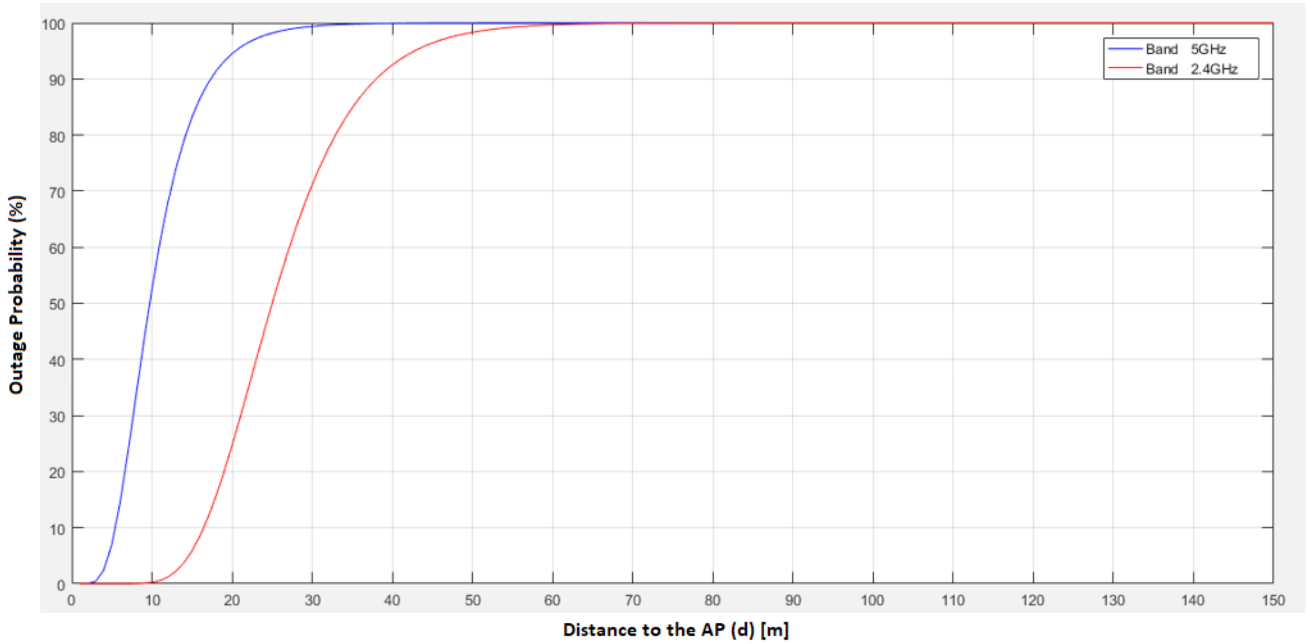

Figure 5. Outage probability in environments with obstacles in function of the band frequency.

Figures 6, 7 the curves describing the reception power for scenarios in free space and environments with obstacles based on the 2.4 GHz band and 5 GHz are presented. They can be appreciated that the 5 GHz band provides levels higher attenuation than the 2.4 GHz band to the same reference distance, which is consistent with models of attenuation shadow set in the previous chapter. However, these curves allow estimating the possible radii hand coverage with the likelihood of cutting and coverage area, depending on the level of sensitivity of the receiving

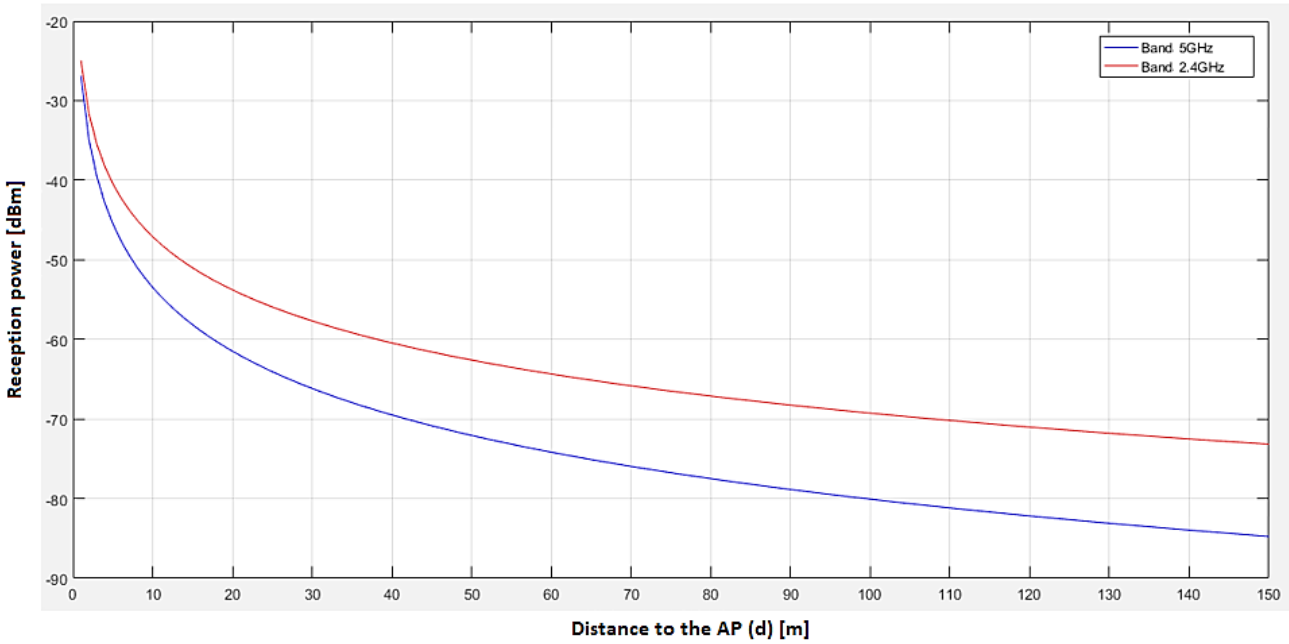

Figure 6. Signal strength in dBm in free space depending on the frequency band.

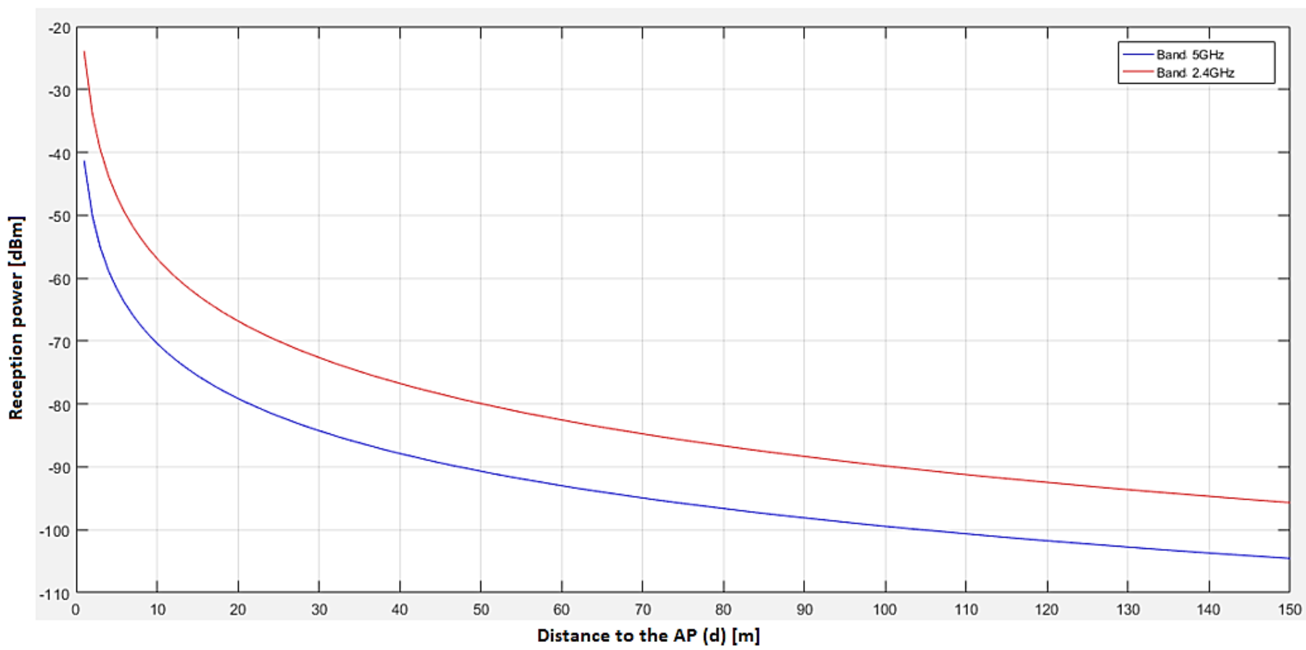

Figure 7. Signal strength in dBm in environments with obstacles depending on the frequency band.

devices, which in most cases for mobile devices are with close to -70dBm and PC and Laptop to -80 dBm values.

Finally, to estimate the average radius of coverage for each of the frequency bands, you can make use of Prob_Corte24G (Pt, type, Pmin, Pc) and Prob_Corte5G (Pt, type, Pmin, Pc) described above functions, which allow the estimation of the coverage area and outage probability depending on the frequency band, type of coverage (free space or obstacles), transmit power and receive sensitivity. In Table 1 the results obtained according to the input parameters required by each of the functions.

Table 1. Estimate the coverage radius, outage probability and probability of coverage for specific design values in the bands 2.4 GHz and 5GHz

DesignParameters	2.4GHz band		5GHz band	
Power Transmission ([dBm]P_t)	26	26	25	25
Kind	**Free space**	**obstacles**	**Free space**	**obstacles**
Sensitivity () [dBm] P_{min}	-70	-70	-80	-80
Prob. Estimated cut ([%]P_c^*	fifteen	fifteen	fifteen	fifteen
Prob. Real cutting ([%] P_{corte}	15.05	18.41	15.12	15,65
Radio Coverage () [m]r	66	twenty	53	fifteen
Signal strength ([dBm]P_r)	-64.27	-65.79	-72.74	-74.66
Coverage () [%]C	94.15	95,00	93.56	94.18

3. Conclusions

During the stage of planifiaci of WLAN networks, estimation of coverage areas and outage probability in each cell established by the AP, play a very important role to maximize coverage levels and location of the AP in Indoor environments. In order to establish appropriate computational method for the estimation of the coverage area and the blocking probability, using propagation model Log-Normal Shadowing, which is one of the most used to estimate levels of RSSI models considered and attenuation in wireless networks, due to its ease of implementation and precision in parameter estimation, considering factors implicitly as part of the environment and in other models are not covered, thereby providing a mechanism to adapt to any environment Indoor. According to the results, it was evident that the developed functions Prob_Corte24G (Pt, Type, Pmin, Pc) and Prob_Corte5G (Pt, Type, Pmin, Pc), will be helpful for the design and planning of wireless networks, which allow to estimate quantitatively the radio coverage of each set cell for each AP, depending on the frequency band, type of coverage (free space or obstacles), transmit power and receive sensitivity; and a graphic description of these two variables behavior may occur under various conditions. In view of the above, the functions performed can be considered as vital tools in future research, in which it is required to perform optimization processes spatial and spectral efficiency, in order to maximize SINR levels and coverage, minimizing interference levels.

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