Aparecium Wi-Fi Planner using Enhanced Indoor Propagation Model

Ali Ghandour[1]
[1]National Council for Scientific Research
Beirut, Lebanon
aghandour@cnrs.edu.lb

Jamal Haydar[2], Ali Hariri[2] and Jad Chahine[2]
[2]Computer and Communications Engineering Department
Islamic University of Lebanon, Khaldeh, Lebanon
jamal.haydar@iul.edu.lb, {hariri.ali.93, jad.chahine4}@gmail.com

***Abstract*—Wi-Fi connectivity, a necessity in this digital era, requires careful infrastructure planning and tuning during installation. In this paper, we propose "Aparecium Wi-Fi Planner", an open-source and cross-platform, Wi-Fi planning software tool based on an enhanced empirical path loss model. The proposed "Enhanced Solah's model" delivers more accurate results than existing models. And hence, "Aparecium Wi-Fi Planner" accurately estimates path loss attenuation, absorption attenuation by obstacles and fading effect. Moreover, the tool integrates the design and development of several algorithms to find full-coverage and optimal access point location with reduced complexity. Aparecium has been thoroughly tested and validated using both simulation and real testbed scenarios.**

***Index Terms*—IEEE 802.11, Path Loss Model, Wi-Fi Planning Tool, Wireless Communication, QoS.**

I. INTRODUCTION

The internet is the great mediator of our lives, carrying not only practical information but also highly personal and social information between friends and peers. Smartphones and other mobile devices are the most used devices to access the Internet due to their inherent mobility feature, thanks to wireless internet access technologies and standards. IEEE 802.11 [1] standard (also widely known as Wi-Fi) is one of the most used wireless technology standards. The adoption use of this technology still faces several obstacles such as the limited coverage area, interference and signal loss. Using many access points in a relatively small area is a costly practice and causes high signal interference.

Thus, providing full Wi-Fi coverage for large enterprises, restaurants, hotels or even residential buildings requires careful planning in order to select the optimal locations to install the minimal needed number of access points. Careful planning requires also to choose the optimal Wi-Fi technology and channels for better performance. The authors in [2] compared different IEEE 802.11 standards (mainly IEEE 802.11a/b/g/n) in indoor environments. Without software tools, this process becomes very difficult and may result in poor planning.

Several Wi-Fi planning software tools already exist in the market. Nonetheless, these tools are expensive and not always affordable. This motivated the implementation of a software tool that ensures efficient Wi-Fi planning, allows the estimation of received signal strength and produces a coverage heat map among other features. We refer to this tool as "Aparecium Wi-Fi Planner". The word "Aparecium", quoted from the famous Harry Potter novels, by Joanne Rowling, is a spell that reveals invisible ink. The tool takes a floor plan as user input and finds the optimal access point location. The developed tool is a cross-platform, light, and open-source software built in JAVA programming language and based on our proposed empirical path loss model discussed in Section III to deliver accurate results.

The contribution of this work is four-folds: *(i)* empirical testing and evaluation of existing Wi-Fi path loss models, *(ii)* introduction of an enhanced path loss model, *(iii)* design and development of an open-source Wi-Fi planning software tool and finally *(iv)* design of two novel algorithms to search for full coverage access point location and optimal access point location, respectively. The notions of "full coverage" and "optimal" access point locations will be discussed in length in Section IV.

The rest of this paper is organized as follows: Section II introduces existing path loss models in the literature and presents the results of our empirical measurements to benchmark those models. In Section III, we propose a new and enhanced path loss model. We discuss the implementation details of the proposed Wi-Fi planning software tool and the two full coverage and optimal access point locations algorithms in Section IV. We evaluate and benchmark the proposed algorithms in Section V and finally conclude this manuscript in Section VI.

II. PATH LOSS MODEL

Indoor path loss models are mathematical equations that can simulate, represent, or estimate the attenuation in a wireless signal during its propagation from emitter to receiver in an indoor closed environment. There are two major categories of path loss models: *(i)* Empirical models that depend on a limited number of variables and used to estimate the path loss attenuation. *(ii)* Deterministic models that consider a high number of parameters and used to simulate wireless signals.

Several deterministic propagation models exist in the literature. For instance, Lee et al. [3] presented a new indoor deterministic propagation model designed to predict the complex temporal and spatial characteristics of the radio channel using ray-launching techniques. Similarly, Dimitriou et al. [4] proposed a site-specific deterministic propagation model that delivers accurate estimations in small running time. Likewise, a dynamic 3-D indoor deterministic model based on ray tracing models was proposed by Ji [5]. Although deterministic models can deliver very accurate results, they are highly complex and require high computing resources. Therefore, for the scope of this work, we focus on empirical models. In the following sub-section, we discuss and benchmark various existing empirical models.

A. *Empirical Models*

Modified Log Normal is an optimized predictive model coined by Sandeep et al. [6]. It can be used to determine the placement and amount of infrastructure required to meet the demands for a network deployment of any size. Whereas there are various propagation models for outdoor network planning, this model is meant to extend the same concept to indoor network planning too. It is in fact a modification of the outdoor Log-Normal path loss model to work in an indoor environment especially for campus networks.

One-Slope model depends on site-survey measurements and assumes a linear dependence between the path loss and the logarithmic distance. This model is simple because the distance between transmitter and receiver is the only used parameter. The mean error of this model reached 3.91dB as reported in [7].

Dual-Slope is an improvement of the One-Slope model to provide better accuracy. This model divides the transmitter-receiver distance into line of sight and non-line of sight ranges. The path loss exponents of each range are determined experimentally as discussed in [7].

Partitioned model is used for residential, office and micro-cells, and defines four different ranges to estimate the path loss. This model uses pre-determined values for the path loss exponents and ranges and delivers accurate results in the first range while the error increases in remaining ranges according to [7].

Multi-wall model defines the path loss as a free space loss, in addition to losses introduced by the walls and floors between the transmitter and the receiver [8]. Path loss calculation depends on the number of penetrated floors and the types of walls, which are either heavy or light.

Average Walls model was designed by Loret et al. [9] to facilitate the radio design work of a wireless local area network by means of straightforward calculations. It is based on a derivation of the free field propagation equation considering the building structure and its materials. The model was tested on a large-scale design of a WLAN network of over 400 access points yielding successful results with a maximum mean error of 7.52dB in 25 selected measurement points.

Solah's model, proposed in [10], is derived from the Partitioned model and adds accuracy to indoor signal prediction while retaining a level of consistency at the same time.

B. *Empirical Benchmark of the Path loss Models*

To choose the best path loss model for our software tool, we carried out an empirical benchmark of the aforementioned models. This empirical study consisted of several scenarios in which we placed an access point in multiple different locations and measured the actual received signal strength at randomly chosen points. Subsequently, we measured the distance between the chosen reception points and the access point and calculated the estimated received signal strength using each of the path loss models. Finally, we calculated the mean error of each model and compared their performance.

For the sake of this benchmark, we used a testbed made of two TP-Link and D-Link access points and an Android based Wi-Fi analyzer. The modeling error is the difference between the actual measured signal strength and the estimated one using that model. As discussed above, we calculated the mean error value based on seven different measurements at different locations.

The results are shown in Table 1 where Solah's model showed the most accurate results in terms of mean error and thus we were interested in using it. Solah's model delivered more accurate results for two reasons: *(i)* Solah's model takes material attenuation of different objects located between the transmitter and receiver into account, *(ii)* the breakpoint distance and the path loss exponents are determined experimentally which provides more accurate results, while other models use predetermined values.

Table 1: Empirical mean error results of various path loss models.

Model	Mean Error (dB)
Modified Log Normal	4.53
One-Slope	4.84
Dual-Slope	4.1
Partitioned	3.8
Multi-Wall	3.95
Average Walls	4.9
Solah's Model	3.25

III. ENHANCED SOLAH'S MODEL

Solah's model [10] is defined in Equation (1), where *PL1* is the path loss at 1 meter, *n1* and *n2* are the path loss exponents of the line of sight and non-line of sight ranges respectively, and *dp* is the break point distance between the two ranges.

$$PL = PL1 + \begin{cases} 10\, n1 \log_{10} d1\,, & d1 < dp \\ 10\, n2\, \log_{10} d2\,, & d2 \geq dp \end{cases} + \sum Material\ Losses \quad (1)$$

In our simulation study, we found that the conditional transition between the two ranges at *dp* induces an abrupt change in attenuation values, which is unrealistic and must be avoided. In other words, the two equations of Solah's model result in a significant difference between the estimated signal power right after dp and right before dp. To avoid such glitches, we proposed the "Enhanced Solah's model" that provides a smoother transition across ranges. The proposed Enhanced Solah's model is shown in Equation (2).

$$PL = PL1 + 10n1 \log_{10} d + 10(n2 - n1) \log_{10}\left(1 + \frac{d}{dp}\right) + X + \sum Material\ Attenuation \quad (2)$$

In the proposed equation, when *d* is much less than *dp*, then $\log_{10}\left(1 + \frac{d}{dp}\right)$ tends to zero and eliminates the non-line-of-sight path loss exponent *n2*. On the other hand, when *d* is much greater than *dp,* $\log_{10}\left(1 + \frac{d}{dp}\right)$ approaches $\log_{10} d$, which eliminates the line-of-sight path loss exponent *n1*. Therefore, when the distance is much longer or much shorter than the break point distance, Solah's model equations hold. Otherwise, both components are used to estimate the signal power which provides smoother transition across ranges. In addition to the above modifications, we introduced a new factor X, a random variable with Gaussian distribution, to account for the fading component, which was not considered by Solah in [10].

We benchmarked the proposed model using the same testbed discussed in Section II.B where we placed the Access Point (AP) behind various obstacles and measured the actual received signal and calculated the corresponding attenuation. Then, we computed the path loss attenuation using the new model and compared the results.

Enhanced Solah's model achieved a mean error value of **2.85 dB**, which is better than all other models discussed in Table 1 in the previous section. Table 2 provides more insight about the different experimented scenarios.

In scenario 1, the access point was placed at a randomly chosen location and the received signal strength was measured and calculated at a distance of 3.5 meters from the AP and without any obstacles in between. In scenarios 2 and 3, the signal strength was recorded at a distance of 6m and 12m respectively with a 25cm brick wall between the AP and the receiver. In scenario 4, the receiver was placed behind a 30cm brick wall followed by a 5cm wooden plate and at a distance of 5m from the AP. In scenario 5, there were 3 wooden doors between the AP and the receiver at a distance of 15.5m. The receiver was placed behind a glass window at distance of 6m from the AP in scenario number 6. Finally, in scenario 7, the AP was placed in one room and the receiver in another, with a middle room in between them. The walls of the middle room were covered by wooden plate. The total distance between the AP and the receiver was 11m.

Large error witnessed in scenario 4 can be considered as outlier for the remaining values but is still considered to compute the mean error. In future work, we intend to consider the reasons behind such large error and check whether it is related to material attenuation values.

Table 2: Enhanced Solah's model detailed empirical results.

Scenario	Distance (meter)	Obstacles (with thickness)	Measured Path Loss (dB)	Calculated Path Loss (dB)	Error (dB)
1	3.5	No obstacles	18	19.6	1.6
2	6	Brick Wall 25cm	30	32	2
3	12	Brick Wall 25cm	35	38.1	3.1
4	5	Concrete Wall 40cm Wooden Plate 5cm	32	40.5	8.5
5	15.5	3 Wooden Doors	45	44.5	0.5
6	6	Glass Window 2cm	31	32	1
7	11	2 Brick Walls 25cm 2 Wooden Plates 5cm	50	53.3	3.3

Our proposed model takes material attenuation into consideration so having accurate material attenuation values in the database is a must in such software tool. Many research papers and documents discussed the attenuation of Wi-Fi signals due to penetration into different materials. Some are approximations of attenuation as function of the thickness of the obstacle, while others give approximations regardless of the thickness of the obstacle [11] [12] [13] [14] [15] [16]. To deliver more accurate results, we took material thickness into consideration upon defining the attenuation. Table 3 shows an example of the adopted material attenuation values.

Table 3: Material attenuation values used.

Material thickness	Attenuation (dB)
Concrete 25cm	13.0
Concrete 40cm	18.0
Glass 2cm	8.0
Glass with metal frame 2cm	12.0
Wood 5cm	5.0
Brick 10cm	8.0
Marble 5cm	6.0
Steel 6.5cm	19.0

IV. APARECIUM WI-FI PLANNER

Based on our proposed path loss model, we present Aparecium Wi-Fi Planner tool. It is a cross-platform, open-source desktop application developed in JAVA, with an SQLite database that stores information about materials and their relative attenuations and access point models. Aparecium Wi-Fi Planner provides several interesting features such as reading CAD files, saving and loading planner files, drawing a heat map and finding best location for access points. We developed and implemented several algorithms to make this tool work efficiently.

The user can either draw a floor plan using the drawing tool provided in the application or import a floor plan from a CAD file. The user then defines the materials of the walls inside the plan and their thickness. The tool allows the user to manually place an Access Point (AP) and check the signal strength at different locations or draw the heat map. Alternatively, the user can use the proposed full coverage or the optimal location algorithms to let the tool automatically decide on the access point location. The proposed algorithms are explained in the following subsections.

A. *Full Coverage AP Location Algorithm*

Aparecium Wi-Fi Planner can be used to identify suitable locations to install wireless access points. For this sake, we define the full coverage location as: **the AP installation location which results in a received signal strength that is higher than a predefined threshold over the whole area of interest**.

There might be more than one full coverage location, only one, or none at all. To solve for the Full Coverage AP location, our proposed algorithm will first detect the outer walls of the floor plan to place the AP only inside the floor.

The floor plan is treated as a 2D canvas made of a set of rows and columns where the algorithm follows a simple brute-force approach. It considers first the center of the floor plan as the center location usually has a high probability of providing full coverage. If not, it starts its search space from the top left corner of the canvas and moves s pixels to the right in each iteration, until a full coverage location is found. At each iteration, the algorithm makes sure to check that the pixel is within the floor plan.

In order to find an AP location that covers the whole floor plan, we argue that it is enough to ensure that the outer walls of the floor plan are receiving the threshold signal strength. This is because the outer walls are the furthest areas from the AP in the floor plan. Hence, if the Received Signal Strength (RSS) on the outer walls is above the threshold, then we can be sure that the RSS in all other areas within the floor plan is above that threshold.

If the algorithm checks all possible sample space without finding a full coverage location, a message is displayed stating that more than one access point is needed. In future work, we will consider algorithms that places more than one AP, if needed, to achieve full coverage.

The fine-grained search increment variable s can be changed by the user in the application settings. A default value of $s = 1$ means that all search space pixels will be visited. The choice of the increment variable s presents a trade-off between convergence time and accuracy.

B. *Enhanced Full Coverage AP Location Algorithm*

To enhance the convergence time of the full coverage location, we take the worst case in which no full coverage location exists. To reduce the search space, we introduce the following axiom: **If all AP locations that deliver threshold RSS to a specific outer wall, cannot deliver threshold RSS to all other outer walls, then full coverage AP location does not exist.**

Therefore, it is enough to randomly select one outer wall and find all possible locations that deliver threshold RSS to it, then check if any of these locations can deliver threshold RSS to all other outer walls. If such a location was found, then it guarantees full coverage. Otherwise, full coverage location using a single AP does not exist.

Based on this axiom, the Enhanced Full Coverage algorithm randomly selects an outer wall, then for each pixel on this outer wall, it finds all AP locations that deliver minimum RSS. In perfect cases, this results in a circle of 360 locations. However, in realistic cases the signal will be affected by inner walls and other attenuation and fading factors, thus the AP locations will form a polygon of 360 points forming an arbitrary shape. The algorithm then checks whether each of these locations is inside the floor plan or not. If not, the location is discarded. Then, we check whether those locations provide coverage for the other outer walls. If none of these locations can cover all outer walls, the algorithm discards that pixel and repeats the same process on the next pixel on the wall. This process is repeated either until a full coverage location is found, or until all pixels on the selected wall are tested. In the latter case, a full coverage location does not exist and more than on AP is needed.

To sum up, the algorithm tests 360 different locations for every pixel on a randomly selected outer wall. The algorithm repeats this process until it finds a full coverage location or aborts otherwise.

C. *Optimal AP Location Algorithm*

Both previously proposed full coverage location algorithms find an AP position that covers the whole house by Wi-Fi signal, but this location is not necessarily the optimal location, where optimality is defined in the following paragraph.

We define the optimal location as: **The Full Coverage location that delivers the maximum average received signal strength all over the floor plan**.

Accordingly, the optimal AP location algorithm takes as input only the locations that ensures full coverage and calculates the respected average received signal strength on all outer walls then returns the one with the maximum average.

V. EVALUATION

To evaluate the accuracy of the proposed tool and its algorithms, we applied several experiments in a real testbed floor plan that consists of three rooms and a hallway. The floor plan was chosen from a real residential house since Wi-Fi planning for homes is the target application of Aparecium. For each experiment, the AP was placed at a specific location and the corresponding RSS was measured at several positions. Then, RSS was calculated using the Aparecium tool. The measured and calculated values turned to be very close as discussed in the following subsections.

A. *Aparecium Tool Validation*

Figure 1 illustrates experiment #1 where a TP-Link wireless router was placed on the left side of the floor plan and 7 different validation locations were used to measure the real received power and to estimate it using the Aparecium tool. There are different types of materials (obstacles) between each point and the access point. For example, in scenario 1, there is a brick wall while there is a wooden door in scenario 6. The obtained result values are compared in Table 4. The maximum percent error found is 9%, while the minimum is 1.85%. The mean average percent error is 5.4% and the mean average error is 2.3dBm. This means that the proposed model tool is highly accurate. Reported error might be partially related to the used material attenuation values, in addition to existing fading noise.

In experiment #2, a D-Link DIR-300 wireless router was used to test and validate our tool. The actual received power was measured and estimated using the tool at nine validation points. The obtained results reveal a very low error in terms on RSS estimation (3.2dBm mean error and 4.97% average mean percent error) but are not shown here due to space limitation. Several other experiments tests were also conducted using the TP-Link TL-WR741ND Wireless Router but cannot be presented here.

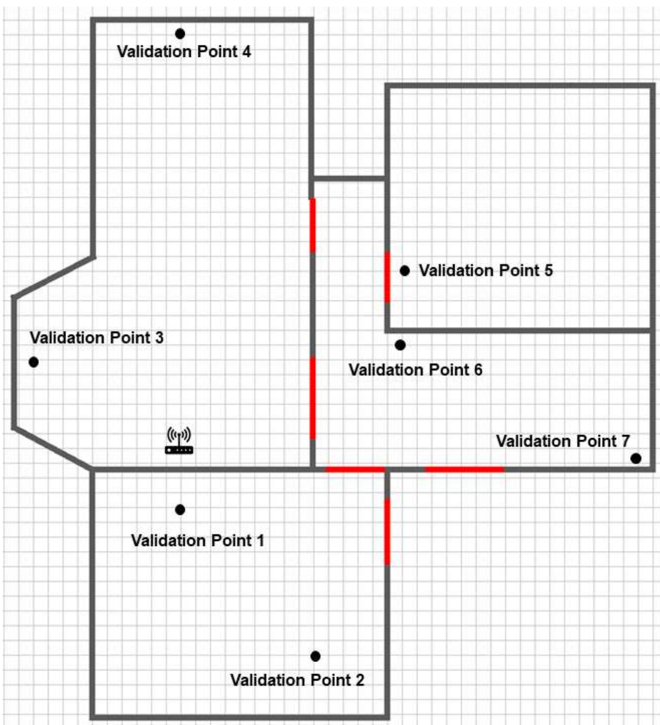

Figure 1: Floor plan used for evaluation.

Table 4: Results of Experiment #1.

Validation Scenario	*Measured RSS (dBm)*	*Calculated RSS (dBm)*	*Percent Error*
1	-43	-41	4.65%
2	-53	-48.2	9.06%
3	-39	-40.2	3.08%
4	-45	-42	6.67%
5	-54	-53	1.85%
6	-47	-44.8	4.68%
7	-54	-49.7	7.96%

B. Enhanced Full Coverage AP Location Algorithm

In order to calculate the needed time in the worst case for the enhanced full coverage algorithm, we used the same floor plan shown in Figure 1 and set the minimum threshold to -40dBm to ensure that full coverage cannot be achieved. The algorithm took 2.7 seconds on a modest laptop with Intel Core i5 to figure out that there is no AP location that can guarantee full coverage. Subsequently, we used the brute-force algorithm with the same configurations, and it took 15 minutes to find that no AP location can guarantee full coverage. This experiment shows the effectiveness of the enhanced full coverage algorithm in delivering accurate results with a huge reduction in time complexity.

C. Optimal AP Location Algorithm

To validate the optimal location access point algorithm, we applied it on the same floor plan used in Figure 1. We placed an AP at the optimal location found by the Aparecium tool and measured the received signal strength at all outer walls. The minimum measured signal strength was -62dBm. Subsequently, we moved the AP to several other locations and measured the received signal strength at all outer walls. For all locations, we found minimum value of less than -62dBm received power.

D. Comparison with Existing Tools

In the following, we briefly introduce three of the most relevant and used Wi-Fi planning tools and compare them to Aparecium in Table 5 using the following criteria: *(i)* Operating System support, *(ii)* Host System Requirements needed to run the tool, *(iii)* Cost in USD, *(iv)* Software License and *(v)* 802.11ac support. Those tools are FortiPlanner, Ekahau Site Survey and Air Magnet Survey.

Table 5: Comparison between existing Wi-Fi planning tools.

	Forti Planner	*Ekahau Site Survey*	*Air Magnet Survey*	*Aparecium*
OS	Windows	Windows	Windows	Any
System resources	High	Very high	High	Very low
Cost	$2000	$2300+	$2500+	Free
License	Proprietary	Proprietary	Proprietary	GNU GPL
802.11ac Support	Yes	Yes	Yes	Yes

VI. CONCLUSION

We developed a cross-platform, open-source, light software tool that allows efficient Wi-Fi planning. The tool takes a floor plan as input either by the integrated drawing tool or by importing a CAD file. The major features and functions of this tool can be summed up by estimating the received signal power at different locations, producing the heat map for one or more access points, or finding the optimal or full coverage AP location. The data required for this tool such as access point models and materials are stored in an SQLite database, which is very light and efficient for small data. The proposed tool was entirely written in JAVA and is available on github (https://github.com/HaririAli/Aparecium). We have also devised several efficient algorithms to make our tool work efficiently. Wi-Fi signal estimations are obtained using an empirical path loss model proposed by us. Empirical studies using different test scenarios reveal both accurate and efficient results. A video of the most relevant features of the tool can be found on YouTube (https://youtu.be/JkMUTtJqMG0).

The tool can be further developed by adding the ability to find optimal locations for multiple access points in large floor plans. One of the proposed ideas for that, is to split the floor plan into 2 smaller plans and find the optimal location for each one of them. The challenge here is to know how to split the plan in order to maintain efficient Wi-Fi planning. In addition, the enhanced full coverage algorithm can be improved by reducing the search space more. One possible solution that is worth exploring, is to find all the AP location polygons of all outer walls, then find the common area between the polygons. The full coverage location must be within this area. Furthermore, the tool can be developed as a web application to make it accessible for everyone anytime and without the need of any local computing resources.

REFERENCES

[1] B. P. Crow, I. Widjaja, J. G. Kim and P. T. Sakai, “IEEE 802.11 wireless local area networks,” IEEE Communications magazine, vol. 35, no. 9, pp. 116-126, 1997.

[2] S. Sendra, P. Fernandez, C. Turro and J. Lloret, “IEEE 802.11 a/b/g/n Indoor Coverage and Performance Comparison,” in 6th International Conference on Wireless and Mobile Communications, 2010.

[3] B. Lee, A. Nix and J. McGeehan, “Indoor space-time propagation modelling using a ray launching technique,” IET, 2001.

[4] A. G. Dimitriou, S. Siachalou, A. Bletsas and J. N. Sahalos, “An efficient propagation model for automatic planning of indoor wireless networks,” in Fourth European Conference on Antennas and Propagation, 2010.

[5] Y. Ji, “Dynamic 3-D Indoor Radio Propagation Model and Applications with Radios from 433 MHZ to 2.4 GHz,” International Journal of Communications, Network and System Sciences, vol. 5, no. 11, p. 753, 2012.

[6] A. Sandeep, Y. Shreyas, S. Seth, R. Agarwal and G. Sadashivappa, “Wireless network visualization and indoor empirical propagation model for a campus wi-fi network,” World Academy of Science, Engineering and Technology, vol. 42, pp. 730-734, 2008.

[7] C. B. Andrade and R. P. F. Hoefel, “IEEE 802.11 WLANs: A comparison on indoor coverage models,” in CCECE, 2010.

[8] COST Action, “COST 231,Digital mobile radio towards future generation systems,” European Communities, EUR 18957, 1999.

[9] J. Lloret, J. J. Lopez, C. Turro and S. Flores, “A fast design model for indoor radio coverage in the 2.4 GHz wireless LAN,” in 1st International Symposium onWireless Communication Systems, 2004.

[10] Y. F. Solahuddin and R. Mardeni, “Indoor empirical path loss prediction model for 2.4 GHz 802.11 n network,” in IEEE International Conference on Control System, Computing and Engineering, 2011.

[11] M. Bugaj, “Attenuation Measurements of Materials Used in Construction of Buildings.,” in PhotonIcs & Electromagnetics Research Symposium, 2014.

[12] CAS Dataloggers Inc., “The Basics of Signal Attenuation,” CAS Dataloggers, 14 November 2016. [Online]. Available: https://www.dataloggerinc.com/resource-article/basics-signal-attenuation/.

[13] D-Link, “Here are some ESTIMATES of wireless signal attenuation through different materials,” [Online]. Available: ftp://files.dlink.com.au/FAQs&White%20Papers/Signal%20Attenuation.pdf.

[14] “How Signal is affected,” [Online]. Available: https://manualzz.com/doc/23311012/how-signal-is-affected--external-device.

[15] K. Ogunjemilua, J. N. Davies, R. Picking and V. Grout, “An investigation into signal strength of 802.11 n WLAN,” Glyndwr University Research Online, 2009.

[16] A. Warycka, “Do Walls Affect Wi-Fi?,” Classrom, [Online]. Available: https://classroom.synonym.com/walls-affect-wifi-16848.html.