



Ziwi: indoor and outdoor planning network—framework to collection, modeling and network structure based on computational optimization and measurements

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Abstract

Society is increasingly connected, utilizing more data that demands greater capacity and better channel quality. Furthermore, wireless networks are being inserted into the population's daily lives. Therefore, solutions capable of transferring a high volume of data are increasingly needed. In this context, we present a framework that aims to network planning through data collection, modeling, and routers optimization in the environment. Ziwi framework can simulate wireless networks in indoor and outdoor environments with the main classical propagation models, obtain and calculate metrics and performance parameters. It is possible to measure data by cell phone and send it to the website quickly. Furthermore, it can model the data and compare with different propagation models. Also, optimize them using a genetic algorithm or permutation, choosing whether or not to consider sockets to turn on the routers and how many routers are needed to place in the environment. In addition, have a virtual reality environment aiming at greater interactivity with the data. We analyzed framework results comparing with Close-In propagation model, free space model, and statically using the root mean square error metric. Measurements were made in a real environment using the Ziwi mobile application, inserting data captured on Ziwi website to validate the framework.

Keywords Wireless network · Mobile networks · Simulation · Propagation · Software

1 Introduction

Over time the population is more connected, through the internet, with objects, and with each other (Skouby and Lynggaard 2014). In the current scenario, due to COVID-

19, video conferences and video streams have increased exponentially since remote work, classes, and meetings are being held virtually, demanding more from internet services. NOKIA's traffic information in the COVID-19 pandemic period showed an increase of 30–50% concerning the peak of “normal” traffic over the weekend (Labovitz 2020).

Video conference applications are the main activity on weekdays and streaming on the weekend. Conference applications like Zoom have seen more than 700% growth in the US since February 1st, 2020. Furthermore, internet services can assist in healthcare by connecting hospitals, ambulances, and homes reliably to make the health service more resource-efficient and more effective in managing Pandemic and normal operations (Saeed et al. 2020). Moreover, services such as remote monitoring and patient diagnosis enabled for artificial intelligence allow anyone with a medical condition to report a central health system without having to be physically present (Shakir 2020). Besides that, applications based on artificial intelligence

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and wireless chipsets/sensors are intended to diagnose whether a person is infected or not (Maghdid et al. 2020).

Due to the rise in the number of online services, such as streaming and video calls, the necessity of mobile and Wireless Local Area Networks (WLANs) with a good connection has increased (Sharma and Wang 2019). Therefore, there is a growing demand for coverage at any time and place without interruption, leading to a need for mobile networks and Wi-Fi to deal with greater capacity and offer the quality required by customers. Operators are implementing new external cells, and routers are experiencing increasing speed (Rappaport et al. 2013). Due to this fact, the demand for an adequate tool for network planning arose to assist in predicting and optimizing signal coverage (Rodrigues et al. 2011).

Rodrigues et al. (2011) shows the growth of services that need the internet and require increasingly complex data. Since 2011, devices such as smartphones, urban and industrial sensing devices have been used by 9 billion people (Huang et al. 2020). The significant increase in data traffic puts huge pressure on network management. Hence, it is noticed the importance of carrying out good network planning, aiming at future network generations.

In this context, this paper aims to develop an easy and practical framework named Ziwi for engineers and academics in the field. Providing an intuitive interface for planning mobile and Wi-Fi networks. Ziwi has a graphical web interface that allows communication with a mobile application capable of measuring electromagnetic signals in indoor and outdoor environments. In addition, allows the use of virtual reality software, aiming to increase the interactivity of the user with the signal of the environment and assist in its analysis.

The developed Ziwi framework helps manage the high data consumption required by 5th Generation of Mobile Communications (5G), smart cities, and by the increase in data traffic due to the COVID-19 Pandemic (Ijaz et al. 2016). In addition to increasing user productivity from an interconnected software that both brings agility for research and increasing user interactivity with the electromagnetic signal through virtual reality.

Ziwi was inspired by the Ranplan (Charbonneau 2005) and IBWave (Qin et al. 2011) simulators. Ranplan performs indoor, outdoor, and hybrid networks planning and IBWave can perform indoor networks planning. Both aim to improve network coverage in 5G scenarios. However, both software are paid and focused on large projects, such as smart cities and smart hospitals that provide real-time treatment. Situations in which significant investments are available. In this context, the main difference between Ziwi and these softwares is that it is free software that can be used in different scenarios. Besides, Ziwi has a mobile application to measure data in indoor and outdoor

scenarios. Furthermore, the website of the Ziwi can optimize the planning, and the framework has a virtual reality system to encourage and facilitate the learning of new students in the area.

This paper is organized as follows: Sect. 2 showed related works and their differences from the current work. Section 3 shows all technologies applied. Section 4 describes the framework development. Section 5 describes the experimental environment configuration, followed by experimental results. Finally, in Sect. 6 we provide our conclusion.

2 Related works

This section provides an overview of the main related works to this research.

Kar et al. (2016) developed an indoor simulator for the Motley Keenan propagation model. However, the software is limited to only Motley Keenan models and outdated internet standards such as IEEE 802.11a, IEEE 802.11b, and IEEE 802.11g. Besides, since it does not have a graphical interface, it makes the simulation process more complex. It is not possible to optimize the router position in the environment. The application differential is to provide signal strength, path loss, Signal-to-Noise Ratio (SNR), Signal-to-Noise-plus-Interference Ratio (SINR), and channel capacity metrics. These data also were inserted in Ziwi. When observing McEl-Roy et al. (2007) work, we decided to add the intensity of the electric field in the Ziwi, so the user can analyze the data and compare with the legal limits of electromagnetic field exposure.

Furtado et al. (2016) created a simulator for the WLAN network very close to the IBWaves simulator, which provides simulation only for indoor environments and runs on desktop computers. Nevertheless, much data is consumed in outdoor environments through mobile networks. Ziwi has a module that allows both indoor and outdoor environments simulations for planning mobile networks, provided by an application for smartphones that also runs in web browsers.

Najnudel (2004) presents the main propagation models for indoor environments, such as Close-In (CI), Motley Keenan, Floating Interception, and ITU-R P.1238-8. Maccartney et al. (2015) propose Floating Interception model, a propagation model that tends to adapt better to the measured path loss. In this model, two parameters are modeled according to the measurements: alpha (the anchor point) and beta (the slope of the curve). Lastly, Castro et al. (2010) present the main propagation models for outdoor environments: SUI, COST 231, and ECC 33.

All models cited above are semi-empirical, i.e., they need measured data in the environment to carry out the

simulation. However, due to the rapid development of technology, it is possible to conduct environmental measurements using applications compatible with mobile devices. Bhatt et al. (2016) present a literature review of the main applications developed with this focus. However, most of them are capable of recording only the signal strength but not generating data logs. Therefore, we developed a measurement application for the Ziwi framework to capture the mentioned metrics and save them in log files.

None of the works presented above perform router optimization. However, some commercial software does this, such as “Raplan” and “IBWave”, which can plan networks for the future generation automatically, optimizing the time of the network planner. Thus, we realize that it would be necessary to implement an optimization technique to plan indoor environments to have the largest network coverage using the shortest possible time.

Teixeira et al. (2017), uses neural networks to predict the signal, but this technique requires training sets, which may not be a viable solution for different situations. On the other hand, Kelly (2016) uses Particle Swarm Optimization (PSO) to find the optimal solution to the problem. Nevertheless, Genetic Algorithms achieve a more accurate solution due to genetic parameters intensifying and diversifying the solution population (Garcia-Martinez et al. 2018). Consequently, we applied genetic algorithms as an optimization technique, which also seeks the optimal solution. Despite spending a little more time than the PSO technique, it tends to have a more accurate result.

Several researchers have used genetic algorithms to optimize routers' positions. For example, Teguh et al. (2014) presented an optimization technique for routers based on energy restriction using a genetic algorithm. The optimization uses routers' positions to minimize total communication distance, aiming to maximize sensor network lifetime. Results found that it is possible to reduce both the number of disconnected sensors and total communication distance.

In (Gao et al. 2013), is proposed a multiobjective genetic algorithm to optimize network coverage for mobile cellular users. First, is assessed the status of cell coverage using measurement data reported by mobile stations. With this, is generated a system to optimize network coverage for users. The results showed that network coverage performance could be improved after optimization with the genetic algorithm. Optimization with a genetic algorithm is not limited to routers. It can also be applied to antennas. Chou et al. (2016) implemented a genetic algorithm in the antenna structure measurement system to optimize them, radiating the directional beam in the desired direction. The actual outputs of the phase shifters are fashionable, so they

can be used to optimize the pattern in real-time, without the need to measure the phase changes of all phase shifters.

For situations where high computational performance devices are not available, semi-empirical propagation models are more appropriate. However, this approach requires measured environment data as the basis demonstrated by the authors in Blackard et al. (1993), where measurements took place in indoor environments, using both omnidirectional and directional antennas. With that, it was possible to analyze the characteristics and sources of noise in the channels. The results are shown in peak amplitude probability distributions, pulse duration distributions, and time distributions between arrivals.

Measurements must also be made in outdoor environments. Liechty (2007), performed measurements in an outdoor environment on a 2.4 GHz IEEE 802.11g Wi-Fi network to validate the Seidel-Rappaport propagation model adapted by the authors. The measurements showed that predictive planning for network coverage is possible without the need for overly complicated modeling techniques, such as ray tracing, and the use of semi-empirical techniques is valid for this.

Many surveys use the G-Net Track Pro mobile application to perform measurements (Yudha et al. 2016), (Alias et al. 2016). However, this application is paid. There is a free version, but it is possible to generate only Reference Signal Received Power (RSRP), Reference Signal Received Quality (RSRQ), and SNR values. Besides, the application only performs measurements in outdoor environments.

Bhatt et al. (2016), showed some applications capable of performing measurements in environments, but most are no longer available or have an intuitive user interface. Thus, to provide these measurements, we developed an application that communicates with the framework.

We present in this section the literature review, detailing the differentials of the proposed simulator. The main points were to use indoor and outdoor propagation models on a web platform. Furthermore, all models implemented in the framework are semi-empirical. Therefore, we developed a mobile application capable of performing measurements for the simulations. A Ziwi differential is that it simulates the heat map of the environment in virtual reality, facilitating its analysis and helping learning in the area of signal propagation, making it more interactive. According to Wickens (1992), virtual reality applications can increase long-term user learning retention and improve performance in a specific area. Thus, it can be used to explain electromagnetic and propagation signals in classrooms.

3 Ziwi's tools

In this section, we demonstrate the tools' concepts and how they are used in the framework. These concepts are wireless networks, propagation models, and optimization techniques.

3.1 Wireless network

At the end of the last century, WLAN communication technologies became popular in the market, with the arrival of the IEEE 802.11 standard. Today, this well established technology composes data infrastructure of communication solutions for the most diverse environments due to its relatively low cost and ease implementation (Ahmavaara et al. 2003).

It is possible to use several IEEE 802.11 standards in the framework, such as 802.11n, 802.11ac, 802.11ad, 802.11ax, and 802.11ay, changing frequency and bandwidth. The differences between the standards are shown in Tables 1 and 2.

People are increasingly dependent on mobility and connectivity. Through mobile devices, users have information from around the world (Backholm et al. 2013). However, these devices may not always be close to an access point, such as Wi-Fi, requiring other technologies to connect to the Internet. Solutions capable of meeting this demand are the 2nd Generation of Mobile Communications (2G), 3rd Generation of Mobile Communications (3G), 4th Generation of Mobile Communications (4G), and more recently 5th Generation of Mobile Communications (5G).

Nowadays, 4G is the main technology used for outdoor environments, which operates in Brazil's 700, 1800, and 2500 MHz bands. The latest advancement in LTE, called LTE-A PRO, allows carrier aggregation with up to 32 carriers. Each carrier with 100 MHz bandwidth offering a maximum aggregate bandwidth of 640 MHz folded without any additional spectrum or base stations. Increasing capacity allows multiple transmit and receive signals

simultaneously and makes it possible to carry more bits per symbol, improving throughput and better use of the spectrum. Besides, the battery lifetime is approximately ten times longer and has a closer alignment with the 5G to improve security of future networks (Dahlman et al. 2016).

We intend to add the 5G in future updates as it promises to carry up to 1000 times more traffic than the current LTE infrastructure (Beyranvand et al. 2016; Ji et al. 2018). The 5G networks should consume up to 90% less energy than current 4G networks. Connection times between mobile devices must be less than five milliseconds (ms). The number of devices connected per area must be 50 to 100 times greater than the current one.

3.2 Propagation models

Knowing the communication channel is essential when the objective is to carry out a good coverage plan. One way to do this is through propagation models also known as path loss models. Propagation models consist in one or more mathematical expressions capable of predicting the attenuation suffered by the electromagnetic signal during its propagation in the communication channel (Furtado et al. 2016).

There is a wide variety of propagation models, most obtained empirically. Empirical propagation models are based on several measurements and observations in real propagation environments. The equation that represents an empirical model is created to best fit the measured path loss data. For an empirical model to efficiently represent propagation losses in a given environment, it must have its parameters derived from the location characteristics, linked to the system frequency operation and effective antenna heights used for signal transmission and reception (Saunders and Aragon-Zavala 2007).

In an outdoor environment, there are large distances between the transmitter and the receiver. In general, the signal propagation is somewhat predictable. Therefore, if we have information about the topography and the

Table 1 Main properties for different IEEE 802.11 standards available in the simulator

	IEEE 802.11n	IEEE 802.11ac
Maximum data rate	72.2 Mbps (20 MHz, 400 ns) 150 Mbps (40 MHz, 400 ns)	96.3 Mbps (20 MHz, 400 ns) 200 Mbps (40 MHz, 400 ns) 433.3 Mbps (80 MHz, 400 ns) 866.7 Mbps (160 MHz, 400 ns)
Frequency	2.4, 5 GHz	5 GHz
PHY protocol	OFDM	OFDM
Bandwidth	20, 40 MHz	20, 40, 80, 160 MHz
Modulation	64 QAM	256 QAM
MIMO	4 × 4	8 × 8 (UL) 4 × 4 (DL, MU-MIMO)

Table 2 Main properties for different 802.11 standards, in development, present in the simulator

	IEEE 802.11ad	IEEE 802.11ax	IEEE 802.11ay
Maximum data rate	7 Gbps	10.53 Gbps	20 Gbps
Frequency	60 GHz	2.4, 5 GHz	60 GHz
PHY protocol	DMG	MIMO-OFDM	OFDM
Bandwidth	2160 MHz	*	8000 MHz
Modulation	OFDM	MIMO-OFDM	OFDM
MIMO	N/D	*	4

constructions in the terrain, we can efficiently determine the coverage area (Abbas et al. 2012). For the outdoor network design, we implemented the SUI, Cost-231, and ECC-33 path loss models.

The SUI model is an empirical model for radio channel characterization frequencies below 11 GHz, considering an initial distance of 100 m (Lima 2017). Cost-231 considers differences in height between the transmitter (Tx) and receiver antennas (Rx). The location to perform coverage analysis is more recommended for urban environments, using 1 km as the initial distance (Singh 2012).

The ECC-33 propagation model can predict signals in frequencies bands up to 3.5 GHz, with the peculiarity of considering both Tx and Rx antenna gains and their heights, as variables in channel modeling (Abhayawardhana et al. 2005; Ayyappan and Dananjayan 2008). Thus, this model can predict path loss in urban environments, but it is not recommended for rural environments.

In indoor environments, the coverage area has a much smaller coverage radius combined with greater complexity and significant variability of materials, so predicting electromagnetic signal propagation is considerably more complex than in outdoor environments (Sarkar et al. 2003). Therefore, for indoor modeling, was implemented Motley Keenan and ITU-R P.1238-1 path loss models.

Motley Keenan is a complete model for signal prediction in indoor environments with obstacles since it considers both floors and walls (Solahuddin and Mardeni 2011). The ITU-R P.1238-1 model predict signals in a frequency range between 900 MHz and 100 GHz in indoor environments. This model considers reflection and diffraction on fixed objects, transmission through walls, floors, and other fixed obstacles, energy confinement in corridors, people, and objects in motion in the environment (Series 2012). However, both models consider floors and the simulator does not yet have a multi-floor simulation mode.

Some path loss models can be used for both indoor and outdoor environments, they are based on the measured data, and due to not considering walls, they can adapt to both environments. The models implemented are Close-In and Floating Intercept.

The Close-In model is a generic model to analyze propagation signals describing the loss on a large scale in a given environment. This model provides a preliminary prediction for path loss for future 5G systems (Sun et al. 2016, 2015; Maccartney et al. 2015). The Floating Intercept model requires two parameters and is not physically based on the transmitted power of the measurements (MacCartney et al. 2013; Samimi et al. 2015). It has the variables alpha and beta, alpha being the point of interception in dB, and beta is the slope of the line, also with a random variable Gaussian with zero mean (in dB) (Maccartney et al. 2015).

For each model mentioned above, we use metrics to classify the environment better. These metrics are:

- *Path loss* measure how much the signal density is decreased with distance;
- *Signal strength* the amount of signal arriving at the mobile device;
- *SNR* the relationship between the amplitude of the desired analog or digital data signal and the noise amplitude in a transmission channel at a specific point in time;
- *SINR* measure the quality of wireless connections;
- *Electrical field strength* the harmfulness of the electromagnetic field in the environment;
- *Channel capacity* the quality of the internet.

Also, the RSRQ measurements and the Root Mean Square Error (RMSE) of the models concerning the measured data are available. The RSRQ is more reliable to visualize the quality of the signal since it uses the number of resources for that. Moreover, the RMSE is important to know how close the predicted model is to real data.

3.3 Optimization techniques

The metaheuristic optimization techniques are those whose problem-solving incorporates intelligent processes that tend to optimize better the solution obtained (Colin 2007). An optimal problem solution is not always the target of these methods (Arcanjo 2014). Therefore, these methods usually find the best possible solutions to problems, not exact solutions. A metaheuristic optimization technique

called a genetic algorithm (GA) was used to achieve a more precise solution by using genetic parameters to intensify and diversify the population (Deb et al. 2002).

The GA has several steps to be completed, specifically: selection, crossing, crossover, and mutation. The selection methods can be used both in choosing which individuals will be parents and choosing the best adapted to pass on to the next generation (Mirjalili 2019). Each individual is an abstract representation of a solution to the problem. Natural selection is a criterion for choosing the best solutions, eliminating the bad ones, and crossing and mutation techniques to obtain new solutions (Mirjalili 2019).

In this work, we use a genetic algorithm to determine the optimal position for the installation of routers in order to obtain greater signal coverage. Each gene represents X and Y points of the position of the router, having as fitness the quality of the coverage of the signal in the environment. The quality of the coverage represents how good the signal strength is in the environment, and is calculated by Ziwi with the data of measurement, that is, latitude, longitude, and signal strength.

The signal strength shows the quality of the coverage, and the user can define which will be the best for his project. Therefore, the best chromosome will be the one with the most significant coverage of the environment according to the signal strength defined by the user. This chromosome in GA uses path loss as an evaluation method. Each iteration performed the selection by the tournament method, the crossover by binary mask, and a mutation at a rate of 0.1, considering elitism. Each population has a size of 100 chromosomes. The user defines the number of generations for the simulation, the more generations, the more accurate it will be, also increasing the algorithm execution time.

In the developed simulator also is possible to optimize from the permutation, a technique used when defining the possible points to install the access point. In this way, are exchanged the sockets coordinates, and is calculated the coverage of each generated option, showing only the best positions coverage in the environment.

4 Developed framework

This section describes the framework development and functioning. Besides, it explains the use case of each software.

Finally, the virtual reality application can do a simulation with high interactivity and make it easier to perform analyses in the environment. The developed application

can be found at <https://play.google.com/store/apps/details?id=com.lidiexp.ziwi> and the virtual reality application can be downloaded from <https://play.google.com/store/apps/details?id=lidiexpziwivr>. The website can be accessed at <http://ziwi.herokuapp.com/>, which also provides a link to mobile application, virtual reality, and instructions for using each software.

4.1 Mobile application

The application has an indoor and outdoor mode, being different in frequency values and how distance is recorded.

To begin radio channel modeling, it is necessary to perform measurements in the environment. So, mobile applications can make these measurements, being compatible with Ziwi websites or virtual reality applications. Besides, its interface optimization makes the network planning process faster and more accurate. For example, it can capture up to 20 points per second and record localization dynamically and automatically.

In indoor mode, the user can choose between preset frequencies for Wi-Fi currently, 2400, 5200 MHz, or 60 GHz. It is possible to pause the recording between each point to save them in a single file. Indoor measurements based on a Cartesian plane, so it is necessary to insert the X and Y axes at each point recorded. Beyond showing signal strength and electric field strength values in real-time and plotting the history of the last 30 s on a graph, it is possible to export the measurement log to both e-mail and the internal memory of the device.

In outdoor mode, the user chooses between predefined frequencies for LTE, being 700, 1800, or 2500 MHz. The recordings can be made just by walking around the environment, capturing the latitude and longitude of the mobile device. The signal strength values, electric field, and RSRQ are shown in real-time and in a graph with the last 30 s of measurements. It is possible to export both to email and the internal memory of the device. Both interfaces are shown in Fig. 1.

We adopted a top-down approach in the tool development, which consists of starting from an overview, finalization, and summarization of the functionalities of the system and then detailing its subcomponents and most basic functionalities. Figure 2 shows the use case diagram for the mobile application, capable of performing signal measurements, which served as a basis for detailing the structure of the tool.

There is only one stakeholder in the software in question, the user interested in performing the signal measurement, with two primary functions: indoor and outdoor measurement, subdivided into mandatory and optional

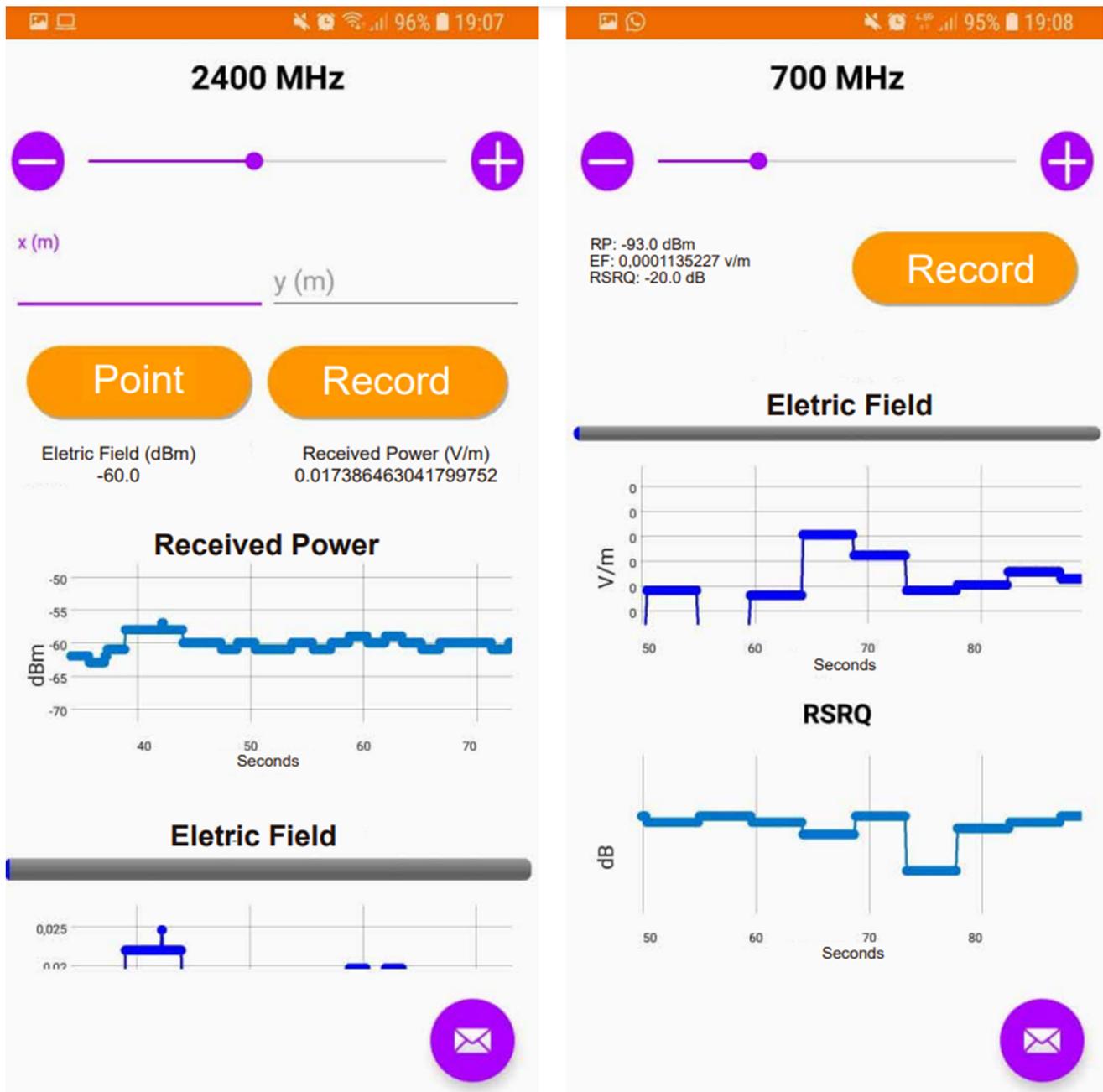


Fig. 1 Mobile application

functions. For example, record data when entered in indoor measurement mode as a mandatory function and send the data by email as an optional function.

4.2 Indoor mode on website

The indoor mode is divided into five sections: simulate models (that generate heat maps), compare models, evaluate the model, optimize the simulation, and create scenarios, respectively, as described below.

4.2.1 First section: indoor mode

In the first section, data on the maximum room width and length (m), the X and Y axis of the routers (m), and the received power at initial point d0 (dBm) are required. There is other information that is also necessary. However, it comes predefined and can be changed, namely: minimum measurement distance (m), transmission power (dBm), frequency (MHz), transmitting and receiving antenna gain (dBi), bandwidth (MHz), and the propagation model to

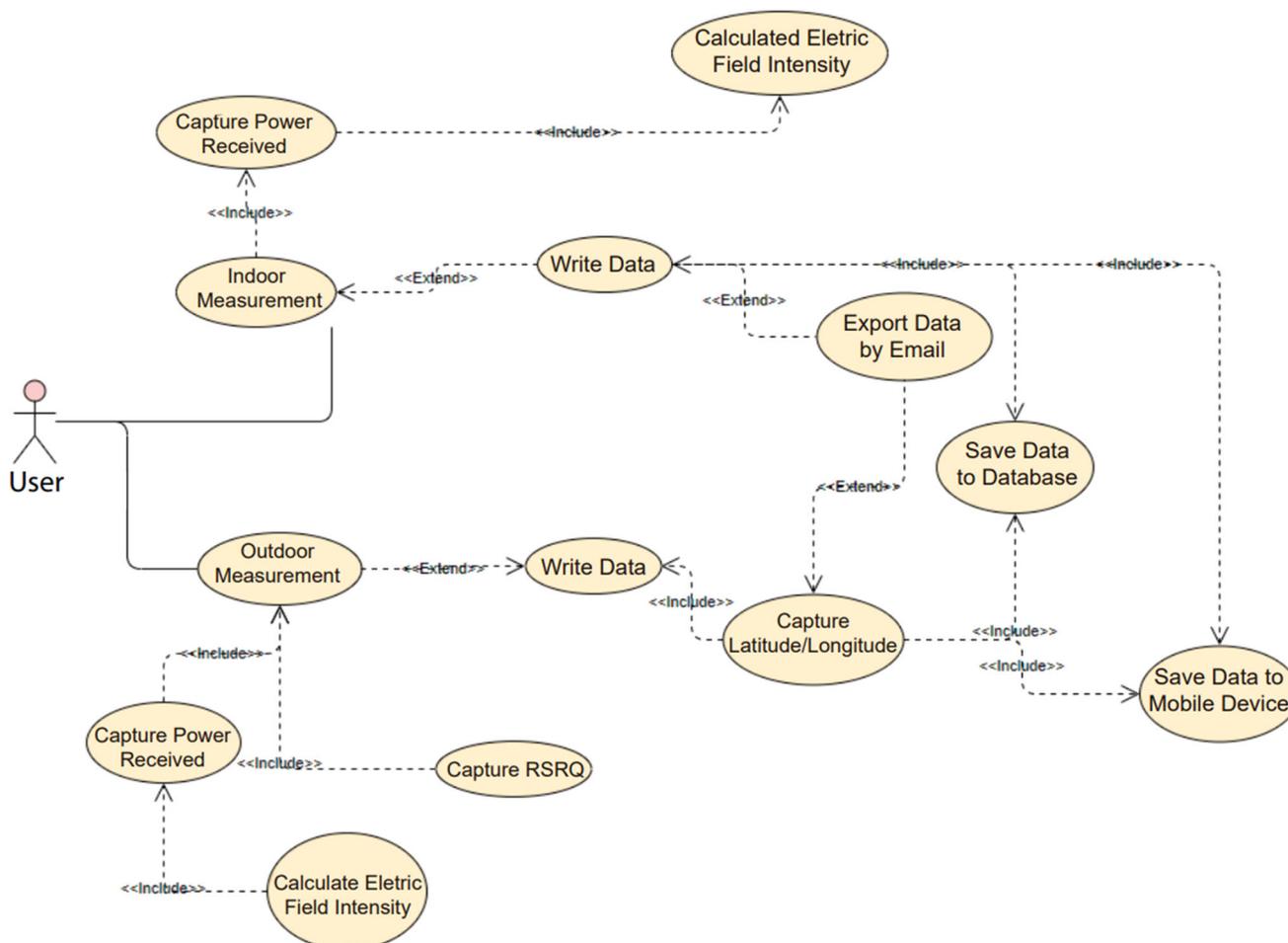


Fig. 2 Use case diagram of mobile application

simulate, being able to choose between Close-In, Floating Intercept, Motley Keenan and ITU-R P.1238-1.

Whether user not defines the environment or using the Floating Intercept model is also necessary to insert the indoor measurement file from the Ziwi application. In addition to inserting the wall file generated by the scenery creation, available on the website itself, this field is only necessary if using the Motley Keenan model since the model considers the walls of the environment. The heat map of the propagation model chosen in the inserted environment will be generated from this data.

4.2.2 Second section: indoor mode

The second section can compare the main propagation models with the measured data and perform the main calculations: the value of path loss exponent and the standard deviation to the measured data.

It is necessary to enter the point values X and Y of the router (m), the environment where the measurements took

place, and the indoor measurement file, generated by the Ziwi mobile application. Some information is predefined by the application, but can be changed according to the needs of the user, such as: frequency (MHz); the first point distance measured (m); transmission power (dBm), and the receiving and transmitting antenna gain (dBi). The simulator uses this data to adequately calculate the radiated power. Figure 3. shows the comparison mode.

When comparing models, the comparison graph among the propagation models and the measured data.

4.2.3 Third section: indoor mode

This section is generated automatically after comparing the data in the second section above. The third section presents the dispersion graph of path loss exponent and a table containing the path loss exponent value and standard deviation for each model, according to the comparison made in the Sect. 4.2.2.

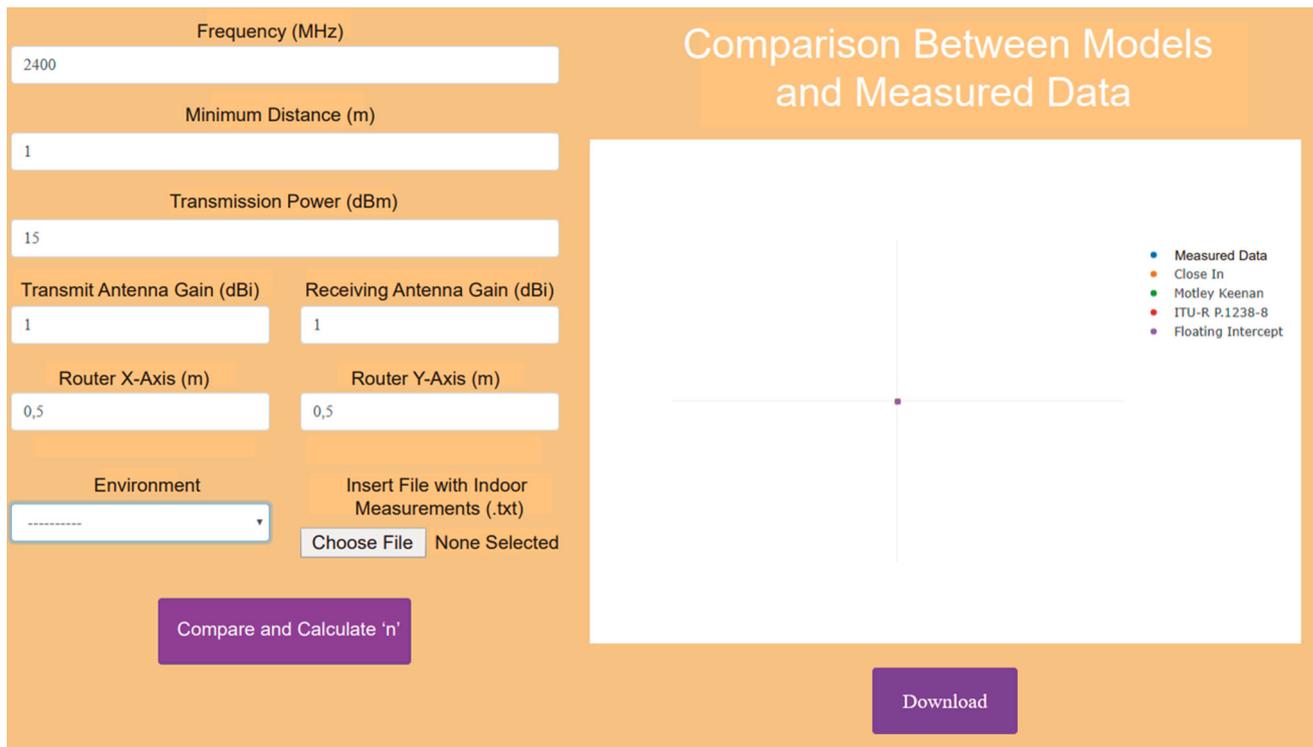


Fig. 3 Comparison mode—indoor mode

4.2.4 Fourth section: indoor mode

In indoor mode, the model optimization, and it needs the same information used in the first section. The section aims to help indoor network planning, making the process faster to define the best location for routers. Initially, to do the optimization, the user chooses the propagation model. Then, he will be informed of the best location to install one or more routers. Finally, it can consider sockets locations that routers will be installed.

There are two ways to use this section, considering or not the location of sockets. First, the algorithm performs the permutation between all points X and Y of the sockets if they are considered. Second, it calculates all possible combinations of sockets to inform the user which will be the best combination ultimately. If not considering the sockets, the best location for the routers will be simulated using the genetic algorithm. If the user wishes to consider the sockets, he must select the “with sockets” option at the beginning. Then, inform the X and Y axes of the sockets and the number of routers to insert into the environment. Otherwise, must select “no sockets” and inform the number of GA iterations and quality threshold in dB. These predefined values can be configured according to the needs of the user. The more iterations, the closer to the optimal value the algorithm will be. However, it will take a longer time to get the results.

A heat map of the last route will be generated with the best result when performing the simulation. Below the title and best positions for the X and Y axis will be shown. It is possible to download the heat map of the environment.

If the user wishes not to consider the sockets, the result will be a fitness graph of the genetic algorithm and heat maps with the best location of the router. In addition, heat maps will be generated informing the signal strength, path loss, SNR, SINR, electric field strength, and capacity. It is possible to download all heat maps in a compressed file. Figure 4. Presents the optimization mode.

4.2.5 Fifth section: indoor mode

For the scenario construction, the environment width and total length in meters, both values must be informed and separated by the letter x, without space, e.g., 5 × 7, for an environment with 5 m of width and 7 m of length.

In the central part of the page, a square appears with the exact dimensions of the room. In this square, the user designs his environment, and the software automatically identifies whether the user wants to insert a vertical or horizontal line according to the clicks given. Then the start and end values of the line must be entered and the distance to the edge in meters. For example, when building a wall, lines are created in the square, where the thickest black line

Fig. 4 Optimization mode—indoor mode

represents the concrete wall, the blackest thin line for the wall with the window, and the red line is the window.

On the left side of the page, there are three buttons and a text box. The text box is the interactive history of the environment that the user is building. For example, when creating walls on the canvas, the information will be added dynamically in the text box, informing the orientation of the wall, its coordinates, and material. It is also possible to add or delete lines by typing or removing information from the text box.

Deleting the wall coordinates from the text box will remove the lines on the canvas. However, it may be a line placed a long time ago, so the user no longer knows which line contains the wall information. Therefore, it is possible to select a line and display it on the canvas. In this way, the line corresponding to that information will turn green, and the user can decide if he wants to change it. Finally, is used

the “Download” button to download the information in a text file, used for modeling with the Motley Keenan model. The scenario construction mode is shown in Fig. 5.

4.3 Outdoor mode on website

The propagation models available in the outdoor website mode are SUI, Cost 231, ECC 33, Close-In, and Floating Intercept. The main function of this mode is the comparison among the models and the measured data and calculations of path loss exponent value and standard deviation.

Aiming to perform the simulation is necessary to enter the values of:

- Frequency (MHz);
- Latitude and longitude of the transmitting antenna;
- Transmitting antenna height (m);
- Receiving antenna height (m);

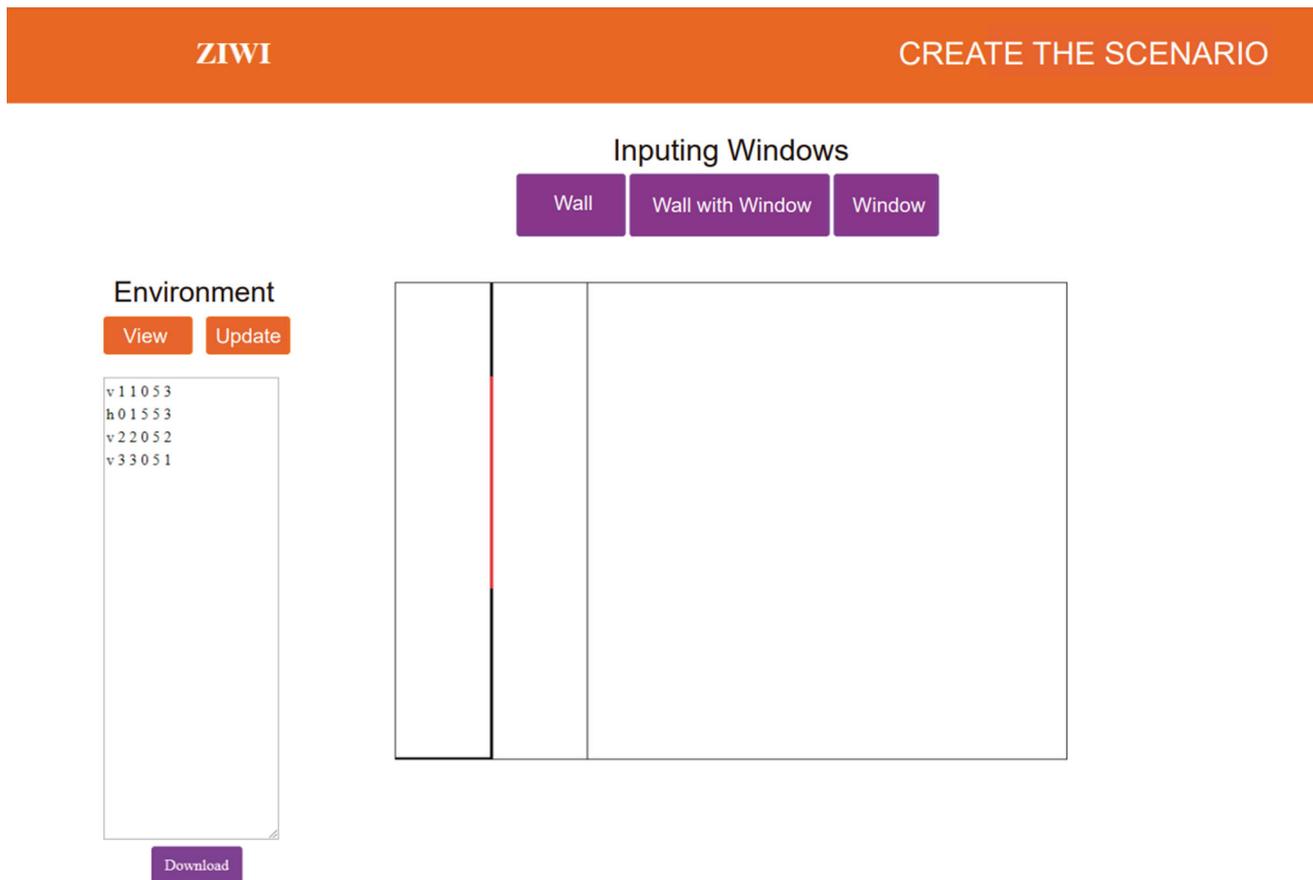


Fig. 5 Scenario construction mode—indoor model

- Transmitting antenna power (dBm);
- The shortest distance that occurred the measurement (m);
- Transmitting antenna gain (dBi);
- Receiving antenna gain (dBi);
- The file with the outdoor measurement values.

The mobile version of Ziwi can export the file with outdoor measurements with the data from the transmitting and receiving antennas used to calculate the adequate radiated power.

For website development, a top-down approach, aiming to present the functionalities of the system briefly and then detail its subcomponents and its most basic functionalities. Figure 6 shows the use case diagram for the website, where are carried out data modeling, comparison, and optimization, which served as a basis for detailing the structure of the tool.

There is only one stakeholder in the software, the user interested in performing signal analysis or optimizing it, and that is the user shown in the diagram. The website has five main functions shown in the image, which have sub-functions that can be mandatory or optional. The mandatory ones include relationship, as is the case when

comparing indoor or outdoor models. Consequently, the calculation of propagation models parameters will be made. The options demonstrate the extended relationship, such as downloading the files after each operation.

4.4 Virtual reality application

Finally, we developed a virtual reality application to visualize data in 3D to make observation more interactive. For example, they can simulate environments and visualize their heat map to the user, informing the X and Y axis of the router and path loss of the point the user is examining. The software also makes it possible to walk around the scene to make the observations more closely.

It is necessary to inform these data to simulate an environment:

- Width and length of the environment to be simulated (m);
- X and Y axis of the routers (m);
- Received power in the shortest distance to the router (dBm);
- The shortest distance to the router (m);
- The transmission power of the router (dBm);

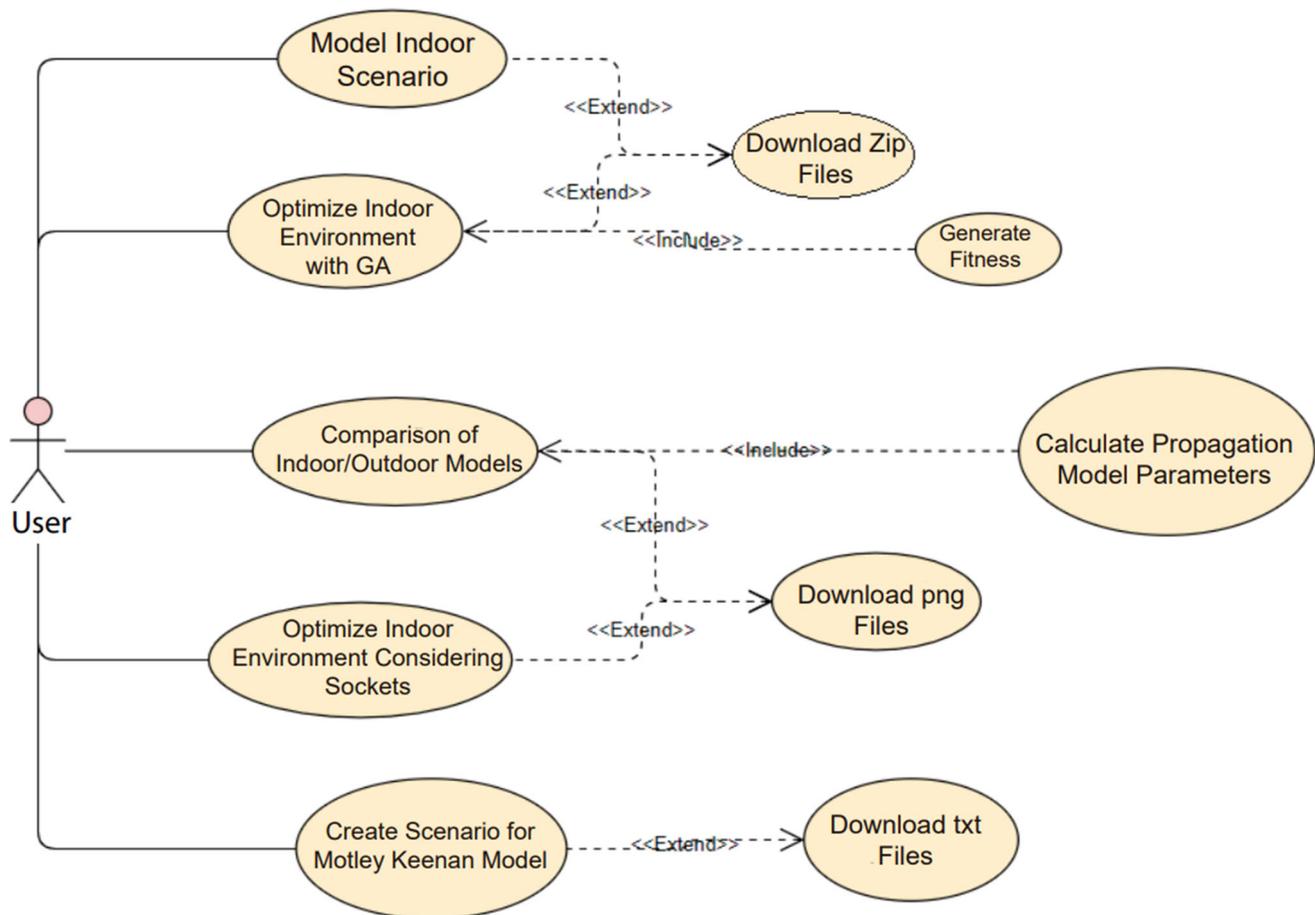


Fig. 6 Use case diagram of website—outdoor mode

- Transmitting and receiving antenna gain (dBi);
- Router frequency (MHz);
- Technology bandwidth (MHz);
- Walls (only mandatory if using Motley Keenan model);
- Path loss exponent (which can be calculated on the website);
- Propagation model (between Close-In, Motley Keenan, and ITU-R P.1238-8).

The user will see the screen where the virtual reality environment will be when entering this data (Fig. 7). It is presented on a heat map on the floor with path loss measures according to the chosen propagation model and environment. Upper left corner shows the value of each color and the user can move around the scenario using the controller and look around with their head. The screen center has a circle that is moved along with the head of the user, when positioned over the path loss, the precise value in the location and the position of X and Y axes are in the upper right corner.

As with previous software, the virtual reality application also adopted a top-down approach in the tool development, aiming to present a summary version of the functionalities

of the system and then detail its subcomponents and its most basic functionalities. Figure 8 shows the use case diagram for the VR application able to view the path loss in 3D, interactively, which served as a basis for detailing the tool structure.

The software has only one stakeholder. He is the user interested in analyzing the signal propagation more interactively, and that is the user shown in the diagram. Its main function is indoor modeling, being divided only into functions that must be performed for the mode, represented by include in the diagram. For example, take the heat map generation in virtual reality and visualize the X and Y coordinates and the path loss in the scenario.

5 Case study

In this section, two use cases of the Ziwi framework will be demonstrated. Initially, in an indoor environment, measurement campaigns were carried out with the mobile application shown in Sect. 4.1. The scenario used for measurement is described in Sect. 5.1. Then, with the

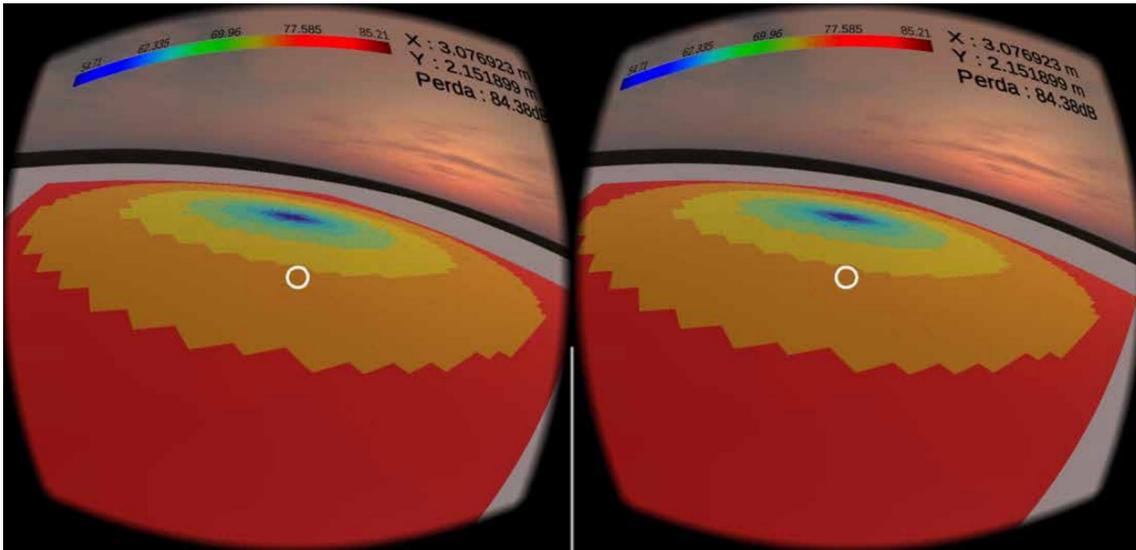


Fig. 7 Visualization of virtual reality application

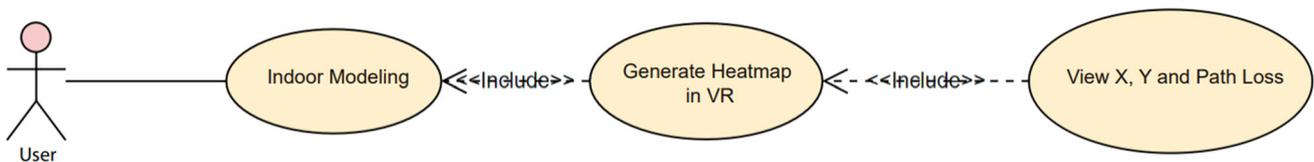


Fig. 8 Use case diagram of virtual reality application

captured data, it was possible to use the tools on the website to generate the results shown in Sects. 5.2 and 5.3.

Also, Sect. 5.4 shows the same scenario being simulated in virtual reality. Finally, measurement campaigns were carried out in an outdoor environment with the mobile application described in Sect. 4.1. The scenario used for the measurements is described in Sect. 5.5. Thus, the captured data were used to compare the outdoor models, the results being shown in Sect. 5.6.

In this way, it was possible to validate the framework of the Ziwi and its accuracy for wireless network applications.

5.1 Indoor scenario

The indoor measurements were made in a classroom at the Federal University of Pará (UFPA). The cell phone was vertical during the entire measurement, with a cross-polarization concerning the router, approximately 1 m from the floor. The room is 8×6 m. The router was installed in one corner of the room, being half a meter from each wall. Therefore, there is also one meter from the floor.

The trajectory performed in the room is shown in Fig. 9. The measurements were made in 3 radials every 1 m of distance, totaling 22 points. The cell phone remained stationary at each point for approximately 10 s, and with the application, it is possible to record 20 points per second.

Therefore, approximately 4400 points were measured across the room.

Measurements were performed using a Samsung Galaxy S9. Moreover, the router used for the measurements was a D-Link IEEE 802.11n standard, at the frequency of 2400 MHz, having an antenna gain of approximately five dBi, and transmission power of 15 dBm.

5.2 Indoor models

In the first section of the website (as shown in Sect. 4.2.1), it is possible to simulate an indoor environment on a heat map according to several metrics, such as signal strength, path loss, SNR, SINR, channel capacity, and electric field strength. In addition to being possible to simulate the environment using the Close-In model, Motley Keenan, ITU-R P.1238-1 and Floating Intercept.

For this simulation, an IEEE 802.11n router was used at 2400 MHz, a transmission antenna gain of 5 dBi, and a receiver antenna gain of 1 dBi. The router was positioned at a half-meter distance from each wall, one meter high from the ground. The router transmission power is 15 dBm, and the received power at point d0 was -43 dBm.

Figure 10 shows the heat map of the path loss in the environment. The signal tends to attenuate as the distance from the router increases. The simulator also generates the

Fig. 9 Measurements performed in the indoor setting

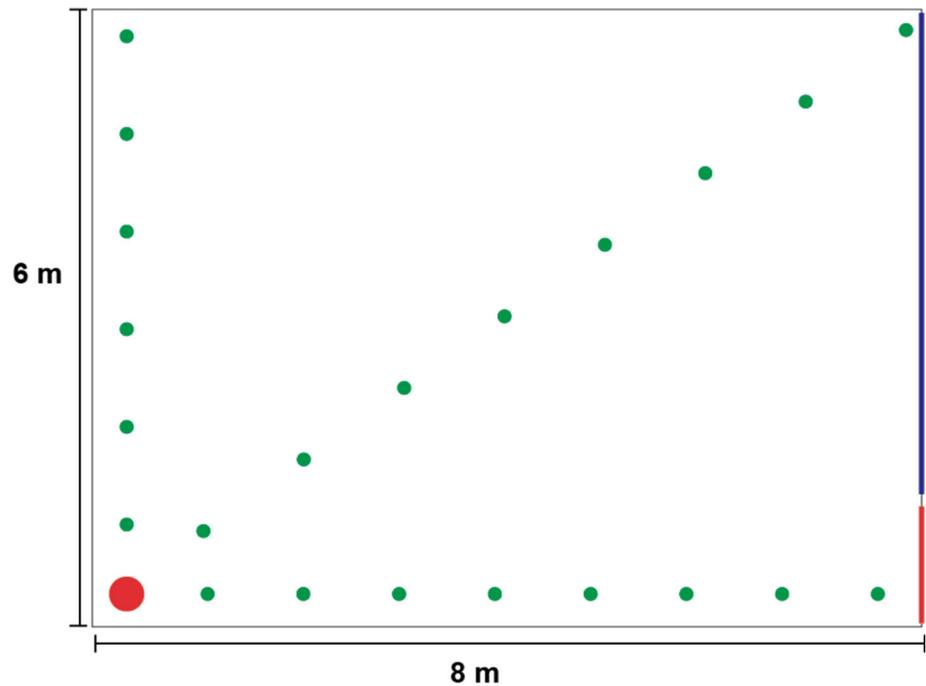
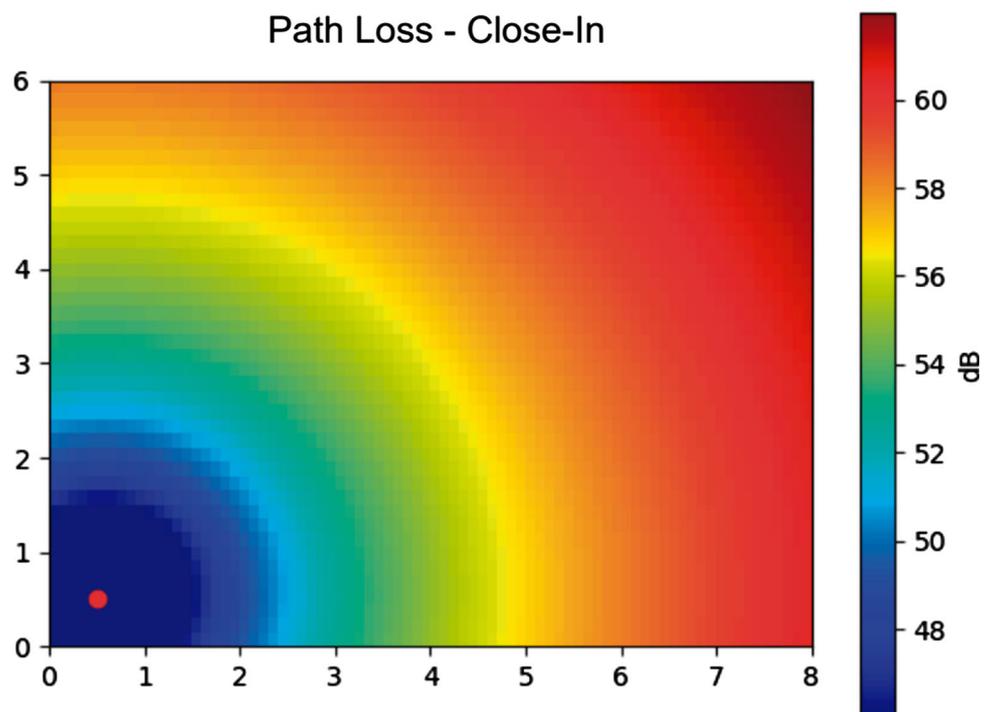


Fig. 10 Heat map of path loss



heat map of the environment considering the signal strength, SNR, SINR, channel capacity, and electric field intensity, aiming to optimize the work of the user by generating simulations for the most diverse purposes.

In the second section, the indoor mode of the website (as shown in Sect. 4.2.2), it is possible to compare all the propagation models available for indoor mode and the

measured data. Needing to be inserted the frequency value, transmission power, received power at point d_0 , antennas gains, routers position, the environment where the measurements took place, and the file with measured data. Figure 11 shows a comparison between the models.

The parameters used for Close-In and Floating Intercept models were calculated from the data entered in the

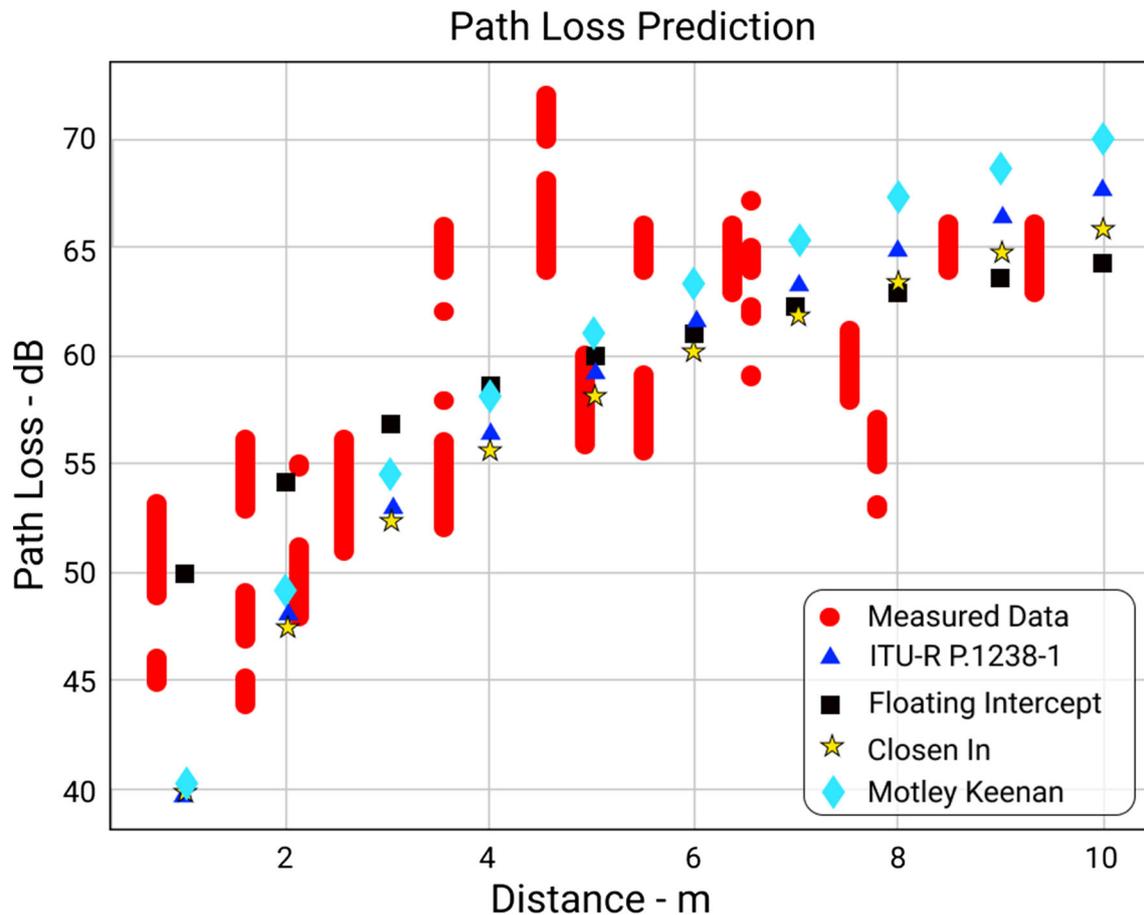


Fig. 11 Comparison between indoor models

system. For the ITU-R P.1238-1 and Motley Keenan models, the attenuation coefficient used was tabulated according to the environment specified by the user, in the case of this work being a furnished environment.

According to the Friis model, the signal loss for 1 m of distance at the 2400 MHz frequency is 40 dB, as shown in the graph for the Close-In, ITU-R P.1238-1, and Motley Keenan models. In the Floating Intercept model, the initial loss was approximately 50 dB, closer to the measured data as the model is based only on measurements of the environment, adjusting to them. As the measurements were made with cross-polarization, the path loss of the environment tends to be greater than with the Friis model.

From this information, the RMSE value of each model is also generated concerning the measured data and auxiliary values (attenuation coefficient and the alpha and beta values used in the Floating Intercept model). The values are being shown in Table 3.

The attenuation coefficient and beta values tend to be close, and the Free Space Path Loss (FSPL) and alpha values representing the curve slope and the initial loss, respectively. The main difference is that the alpha and beta

values are calculated based exclusively on measurements made in the environment.

The RMSE value shows how close each model is to the measured data. For example, it can be seen that the Floating Intercept model was the one that came closest to the measured data as the model depends on two physical parameters to adjust, the alpha and the beta. In contrast, the other models depend only on the attenuation coefficient. The other models, on the other hand, obtained a slight difference between the RMSE.

5.3 Indoor optimization

Through the website, it is possible to optimize indoor environments. The “No socket” mode is the one that uses a genetic algorithm to define the best points to install the routers. The optimization by genetic algorithm aims at closed environments that are still under construction, that is, when it is possible to install sockets in any position. In this way, GA searches for the entire environment where there will be the best points to insert a router, aiming at the best quality of signal in the environment.

Table 3 Comparison metrics of indoor models

	Close-in	Motley Keenan	ITU-R P.1238-1	Floating intercept
Auxiliary	$n = 2.58$	$n = 3$	$n = 2.8$	Alpha = 49.86 Beta = 1.45
RMSE	5.79	5.81	5.72	3.57

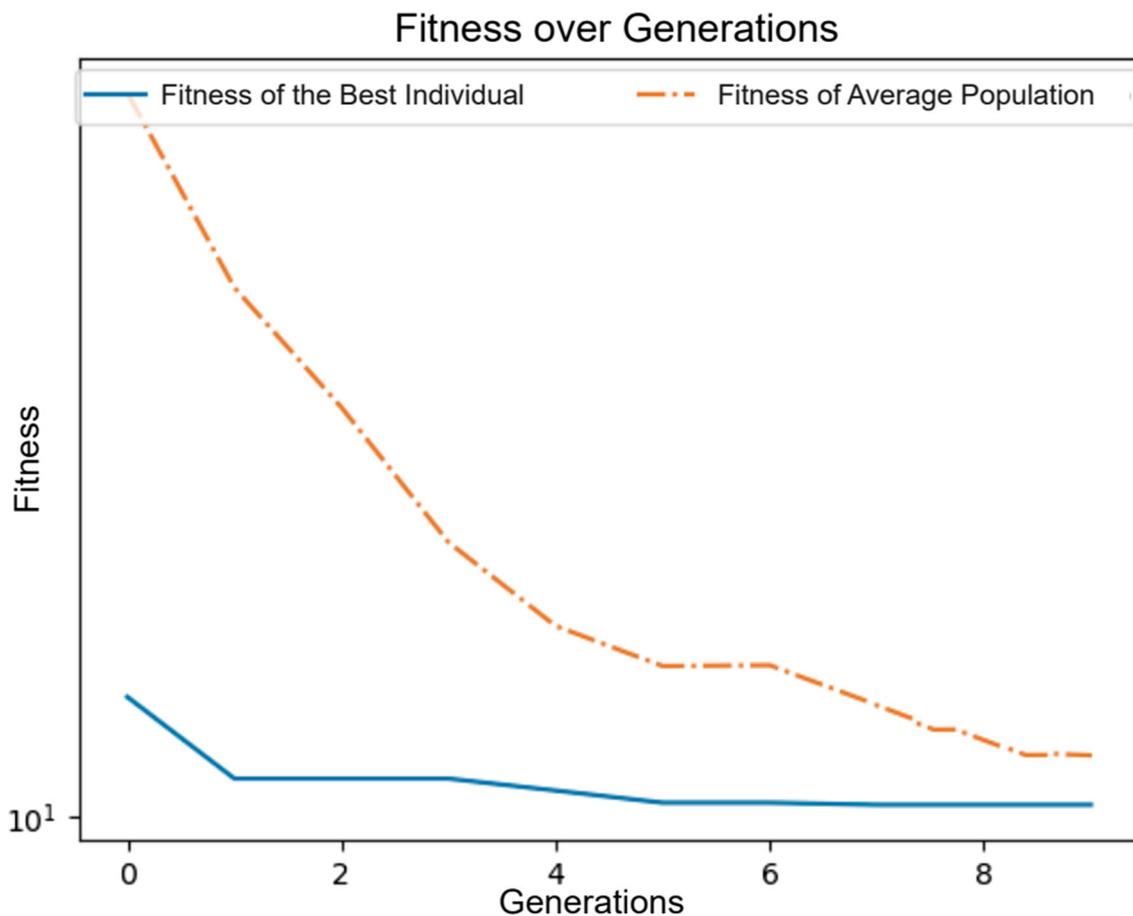
The data required to perform this simulation are the same as in the first section, adding the number of interactions with the genetic algorithm and the quality threshold in dB. Of course, with more interactions, the result will be better. However, it will also take a longer time. Furthermore, the quality threshold is the acceptable received power for the project being optimized.

Figure 12 presents the genetic algorithm fitness curve showing the best individual fitness and the average population that tends to converge in a minimal error over the generations. However, it is also possible to observe elitism in the algorithm, since fitness has continuously decreased over the generations.

Figure 13 shows the heat map before and after optimization. With the position of the router optimization, there was an improvement of 2 dB in the environment.

Also, on the path loss map, it is possible to view the routers' location implemented in the environment and coverage percentage, taking into account the acceptable signal strength defined by the user. For the scenario used in this work, we obtained 89.81% of coverage, with the best location for the router being the point [4.05, 3.01]. There is also the "With socket" mode that performs the optimization with the aid of permutation. This mode is ideal for environments that are ready and need to optimize the signal, as one of the inputs of this method is the location of the environment sockets and the number of routers that will be installed. Thus, the permutation between the coordinates of the sockets is made, generating the X and Y axes of input to simulate which will have the least path loss.

The necessary data are the same as the simulation in the first section, adding the X and Y axis of the sockets and the

**Fig. 12** Fitness throughout generations

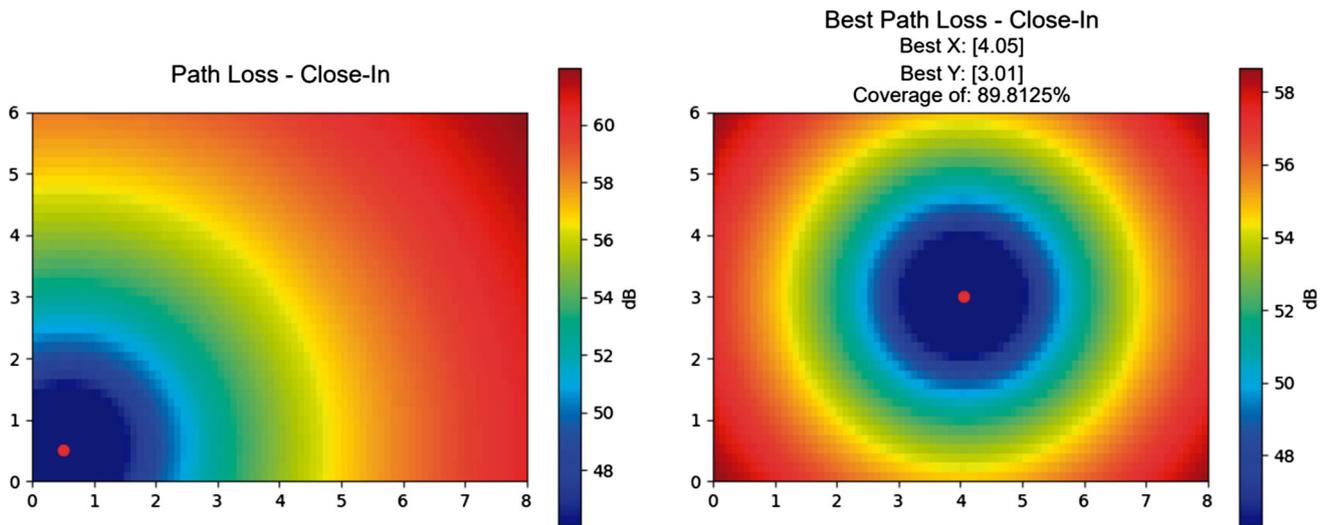


Fig. 13 Heat map of loss between original and optimized positions

router number that is intended to be installed. The simulation is performed between all the coordinates. The simulator exports only the one with the best result (Fig. 14), showing the position of the router in the title text, represented by red dots in the image. The sockets for this simulation were located on the axes [0, 1], [0, 3], [0, 5], [2, 4], [4, 3] and [6, 2].

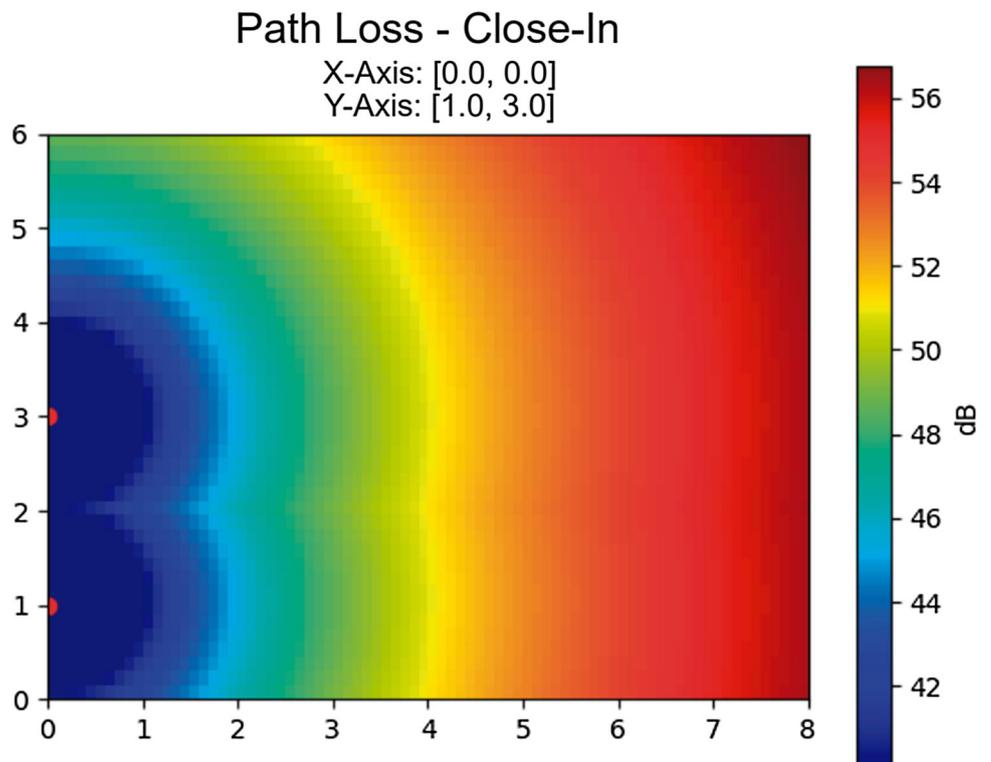
Analyzing Fig. 10 with Fig. 14, it is possible to see from the path loss range in the environment that the loss has decreased considerably. The maximum loss improved from

60 to 56 dB, and the minimum loss was improved from 48 to 42 dB. Thus, this function aims to optimize propagation signals in environments that are already ready and want to improve signal quality or add a new router.

5.4 Virtual reality

A virtual reality simulation was performed using Ziwi with the same environment and settings as previous simulations. Figure 15 shows how the scenario looks as soon as the user

Fig. 14 Optimization considering sockets



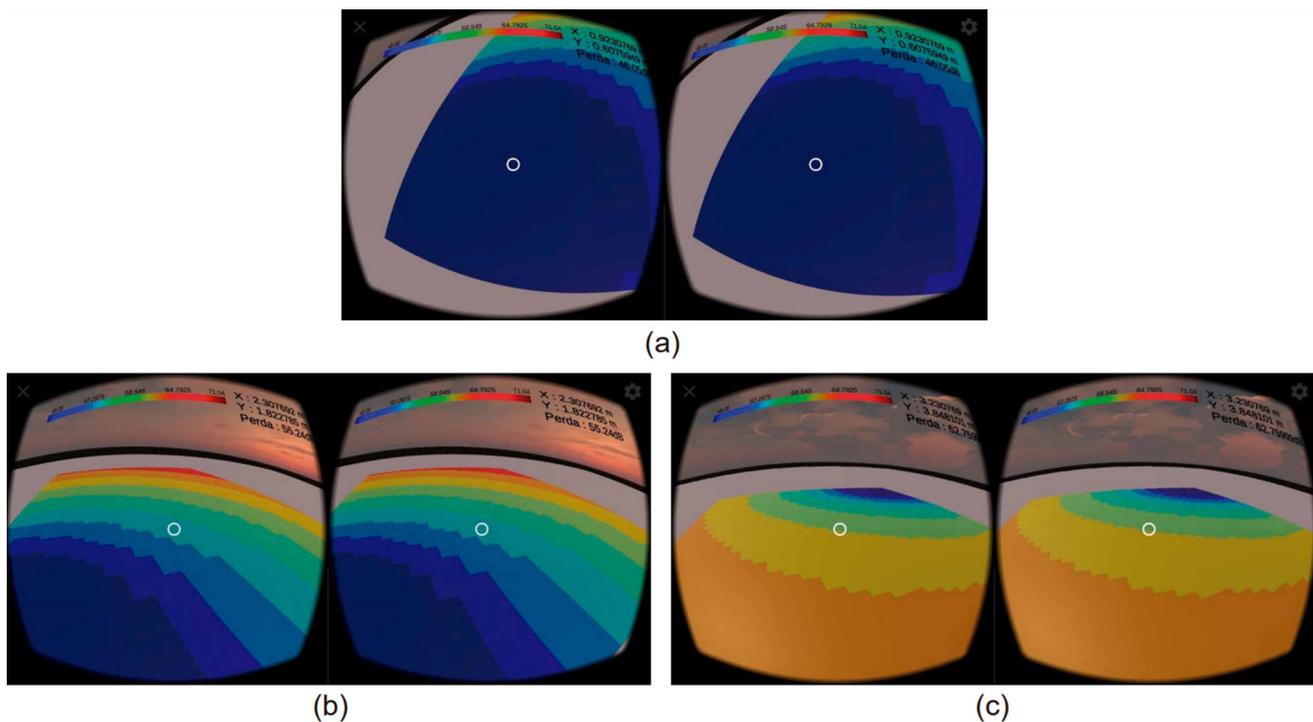


Fig. 15 Virtual reality simulation

enters the environment. For example, Fig. 15a is looking down, and Fig. 15b is looking forward. Figure 15c shows the floor with path loss when the user turns his head to look at the router and walks to the end of the environment to have another view of the scenario. With this, the user can see that the path loss on the router is almost null and increases with distance. As the user will be in virtual reality, he will be able to assess how much the loss increases with distance and the exact loss value at each point.

It is possible to see that in the upper left part, there is a bar that shows the minimum and maximum path loss and the equivalent path loss in the environment. In the upper right part are the X and Y position in meters and the path loss in dB for the point observed by the user. The point is defined for the area where the white circle in the center of the screen is pointing. Observing the upper right area of the image shows the values changes according to the location the user is looking.

The importance of a virtual reality application for the area is both to increase interactivity with the environment as well helping to analyze more complex environments. Nevertheless, it is also essential for the educational area when it will be able to show students in a more interactive way how signal propagation works.

5.5 Outdoor scenario

The outdoor measurements were taken at the Science and Technology Park (PCT) at UFPA, which presents a wooded environment with some constructions along the way. The street just in front of a building was chosen, being approximately 200 m long, totaling 8676 measured points since approximately 20 points are recorded per second. The cell phone was vertical during the entire measurement, with a cross-polarization concerning the transmitting antenna, approximately 1 m from the ground.

The measurements were made using a Samsung Galaxy S9 smartphone connected to an LTE network, a transmission antenna approximately 450 m from the park. The transmission antenna has a frequency of 1870 MHz, a height of 50 m from the ground. It has a transmission power of 60 W, and the antenna gain is 16.71 dB.

5.6 Outdoor models

For the outdoor website mode, a comparison was made between the models and the measured data. The available models are SUI, Cost 231, ECC-33, Close-In, and Floating Intercept. For this simulation, an LTE network was used, whose antenna distance is approximately 450 m from the environment of the measurement. The antenna has a frequency of 1870 MHz, 50 m high, and has a transmission power of 47.78 dB and an antenna gain of 16.71 dB.

It is also necessary to enter the measured data obtained through the measurement of a mobile device. Therefore, the gain of the receiving antenna is 1 dB and defines the environment of a big city since measurements were made in a wooded environment. The models were not made specifically for that environment. Figure 16 compares the models and the measured data. Notice that the graph shows only the Floating Intercept model curve and the Close-In model just below this curve, showing a difference of 0.0032 dB between the RMSE of each model.

The SUI, COST 231, and ECC 33 models were not developed to be applied in wooded environments. Also, these models do not have any physical parameters based on measurements of the environment. The parameters of the models are adjustable for the predefined environments for each one, so the path loss for these models tends to present a more significant error concerning the measured data.

The Close-In and Floating Intercept models are based on physical parameters obtained from environmental measurements, making it easier to adapt to a wooded

environment. According to the Friis model, the path loss for 450 m and 1870 MHz is 150 dB. In the measurement, a path loss of 153 dB was obtained in both models for this distance. There was a minor variation because the path loss calculated by the Friis model is an initial distance of 100 m in an outdoor environment, so there may be a slight variation in the path loss compared to that calculated by the Friis model due to the curve slope.

From this information, the RMSE value of each model is also generated concerning the measured data and auxiliary values, such as the value of the attenuation coefficient used in the Close-In model and the alpha and beta values used in the Floating Intercept model. The values are being shown in Table 4.

The Floating Intercept model was the one that came closest to the measured data. As the environment was wooded and several constructions around, physical parameters, alpha and beta of the model, made it fit better to the environment than the other propagation models.

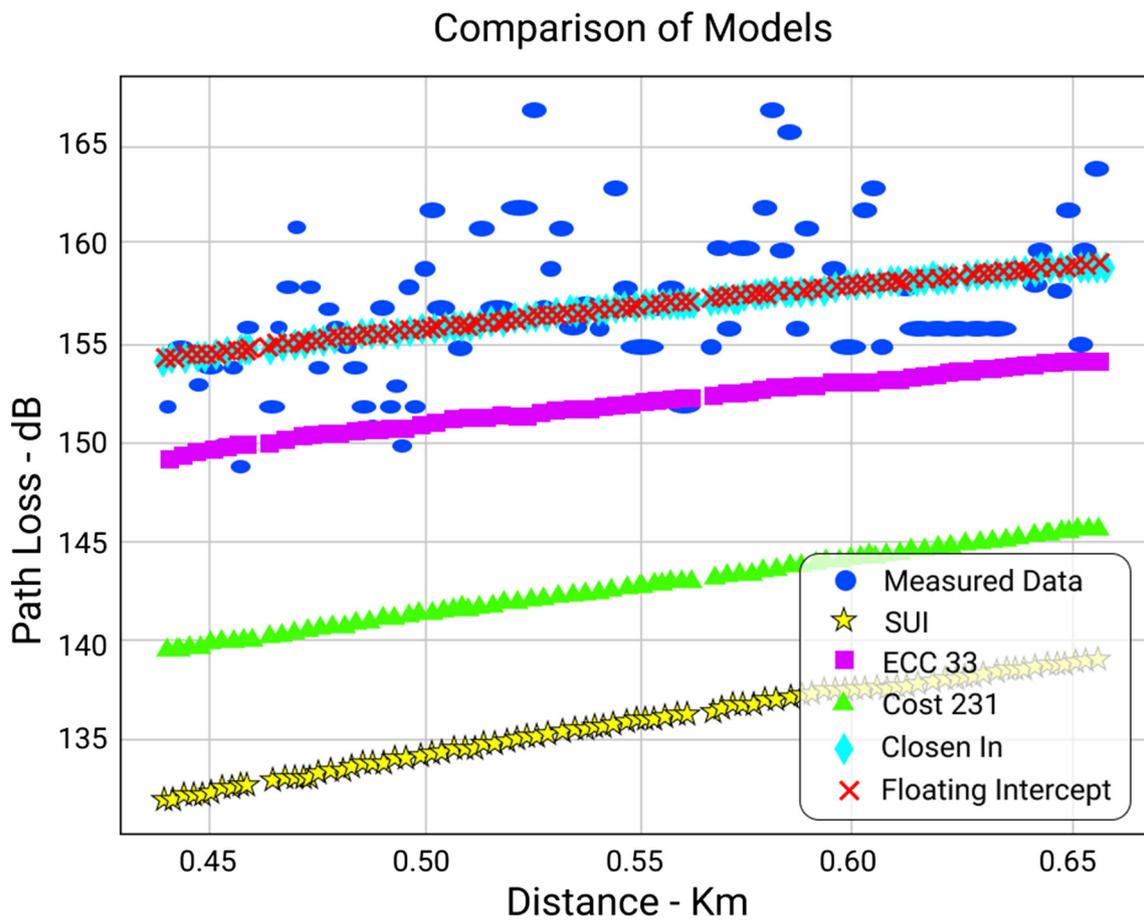


Fig. 16 Comparison between outdoor models

Table 4 Comparison metrics of outdoor models

	SUI	COST 321	ECC 33	Close-in	Floating intercept
Auxiliary	–	–	–	–	Alpha = 163.97 Beta = 2.74
RMSE	21.09	14.1	4.89	2.3994	2.3962

6 Conclusion

This work aimed to develop a framework for measuring, modeling, and planning environments, indoor or outdoor. For this, three software were developed with communication between them for data transfer aiming at the efficiency of the work of a telecommunications engineer, who can do his job faster, without losing quality. In addition to having a virtual reality version aiming to make the signal analysis mode more interactive, it is more attractive for new professionals in the area.

The framework can assist in network planning, making signal modeling, measurement, and optimization faster. Furthermore, assist in the academic and professional area by having a more straightforward and more intuitive interface and analyzing the spread of the environment in virtual reality, increasing the interactivity and understanding of students, researchers and engineers with the content.

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