Indoor propagation prediction software and WLAN measurements at 2.4 GHz

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Abstract – Presented here is software for indoor signal strength prediction. Software parameters and calculation process using beam tracing for fast and accurate prediction are explained. Also given is the measurement equipment and setup used to verify the calculation process in the 2.4 GHz ISM band. Received signal strength was measured inside an office building and calculations on the same environment were done using the prediction software. The measurement results are compared to the calculations over two routes and on several key points.

1. INTRODUCTION

Predicting the propagation of electromagnetic waves has always been a difficult task. It is influenced by many factors in the environment, and the signal from the transmitter usually reaches the receiver by more than one path, making the prediction that much more complex. This is most evident in indoor environments where the receiver most likely does not have a direct line of sight to the transmitter, but is reached by a large number of weak rays, making the prediction process extremely difficult.

Many methods of prediction have been developed, varying in both accuracy and calculation time required [1-3].

The method commonly used in macro- and micro-cell models is a modification of free space formula with added losses for diffraction. These methods are based on experiments, and a good example is the Okumura-Hata model [4]. This model provides parameters for propagation in different environments, and requires the knowledge of the direct propagation path and a single diffracted ray in order to predict the signal strength. It encompasses propagation behind obstacles, but only in the vertical plane. This method offers extremely fast calculation time, but the results are usually far from accurate due to generalizations required. The measurements are taken in different environments. Calculations offer only the mean path loss value observed in those environments. Errors as high as 20 dB have been observed, but the calculations are usually done within a few minutes for the whole map area.

The most accurate models today are based on ray-tracing and predict the propagation of electromagnetic waves along a finite number of launched rays [5-7]. Signal strength is calculated for each of the paths and combined to predict the strength of a given point. Each point in space is significantly influenced by a number of these rays and the number of possible propagation paths is infinite, thus requiring some reduction in searched space. This is usually done by limiting the number of objects in the database to include only those that significantly affect the propagation as the number of objects in the database exponentially increases the calculation time. Higher order reflections, transmissions and diffractions are also rejected although the actual limitations vary with each algorithm. On the overall, these models are highly accurate, but extremely slow, taking between several seconds to several minutes to calculate signal strength for one point.

Presented here is software platform for propagation prediction in indoor environments, developed in MATLAB at the Faculty of Electrical Engineering and Computing, at the Department of Radio Communications. Our goal was to find a fast and accurate method for propagation prediction of electromagnetic waves, and implement it in a network-planning tool that would allow fast prediction for the whole observed area. The software relies on beam-tracing and modified free space propagation equations to calculate the signal strength. Extensive measurements have been performed in order to determine environment variables that should be used in calculations and verify the validity of this model.

Software parameters, calculation process, and graphical interface are explained in chapter two. Equipment and measurement setup, as well as software used for measurements are given in chapter three. Chapter four gives a comparison of calculated and measured results for the twelfth floor of Faculty of Electrical Engineering and Computing. Measured signal strength values are compared to the calculations over two routes. Conclusion and future plans are given in chapter five.

2. SOFTWARE

The software requires map of the environment and propagation parameters to calculate signal strength. Environment map is a file containing coordinates for all objects within the environment, as well as their type and reflection and transmission losses. Any of these parameters can be defined by the user through map editor developed specifically for this purpose.

Propagation parameters required for the calculation include only the most relevant information about the transmitter and receiver. Transmitter parameters include carrier frequency (from which the signal wavelength λ is calculated) and transmitter power (P_{Tx}), as well as transmitter antenna parameters – antenna gain (G_{Tx}), radiation pattern and antenna orientation. Receiver parameters include receiver antenna gain (G_{Rx}), receiver noise figure, bandwidth of the received signal, noise figure and receiver temperature. These are used to calculate receiver sensitivity, which determines minimal signal strength that can be received.

Also required are the fading margin and propagation exponent. Fading margin is an overhead in signal strength required to counter the effects of sudden drops in received signal power caused by changes in the environment (called signal fading). Required fading margin depends on the wanted connection quality, and is usually set between 10 dB and 20 dB for mobile communications. Propagation exponent (R) determines the falloff of signal power density with distance from the transmitter. This value equals 2 in free space, and is commonly used in macro cell models to encompass all of the propagation phenomena. As this software considers all of these, the propagation exponent is used only for smaller objects within the environment that are not included in the environment map and should be set between 2 and 2.5 (the higher values should only be used when a very large number of obstacles is present).

The model uses a modification of the Friis free space formula to calculate the received signal power at a distance d from the transmitter for each ray that reaches the receiver (1). Influence on received signal strength from obstacles within the environment is taken into account through parameter L. This value represents additional attenuation in signal strength caused by propagation phenomena.

$$P_p = \frac{P_o \cdot G_o \cdot G_p}{L} \cdot \left(\frac{\lambda}{4 \cdot \pi} \right)^2 \cdot \frac{1}{d^R} \quad (1)$$

The software considers transmission, reflection and diffraction using geometrical optics to predict signal strength as accurately as possible. The method does not consider single rays like conventional ray-tracing models, but groups rays that encounter the same propagation phenomena into beams. Each beam is represented by a signal image (matrix containing signal strength values for the whole beam area), and appropriate transformations are applied to the whole beam simultaneously, speeding up the calculation process considerably. Unlike ray-tracing which calculates signal strength for each map point separately, beam tracing calculates signal strength for the whole map simultaneously.

The algorithm is based on signal images that cover an area larger than the observed environment. The starting signal image is created for free-space environment using modified free space equation (1) and used to invoke a recursive function. This function searches for objects found in a given signal image for areas where the signal is of sufficient strength for reception. The software then determines which beam encountered the object and separates it into a different signal image, again invoking the recursive function. This is done separately for each propagation phenomena resulting in three new images, which are then combined and used to modify the original signal image. A tree of all possible propagation paths throughout the whole environment is created in this way (fig.1). An advantage over standard ray-tracing methods is that this model retains its accuracy even in the areas farther from the transmitter whereas ray-tracing accuracy decreases the farther we go from the transmitter.

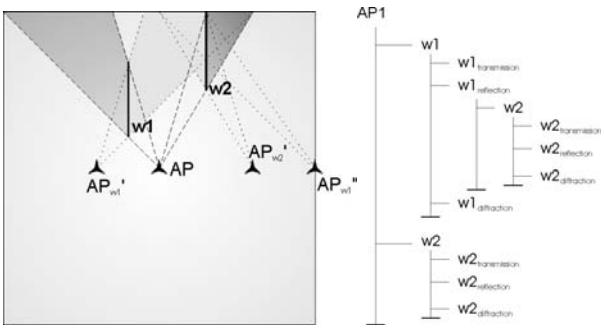


Figure 1 – An example of beam tracing for a simple environment with two walls (left) and the resulting image tree (right)

Graphical user interface is shown on fig.2. Interface is used for input of propagation parameters and for results presentation. Parameter entry fields are placed on the right side of the interface and grouped into boxes, and the propagation environment and calculation results are shown on the left. Areas with insufficient signal strength for a connection of sufficient quality are marked white. The bar next to the signal image enables the user to roughly estimate signal strength in areas where communication is possible. More accurate readings are obtained by simply placing the pointer over the wanted map point, as one of the fields in the interface always shows pointer position and signal strength of the appropriate point. Three-dimensional visualization of the environment and of the calculation results is also possible, as well as a comparison between calculations with and without diffraction, or between calculations using different parameters.

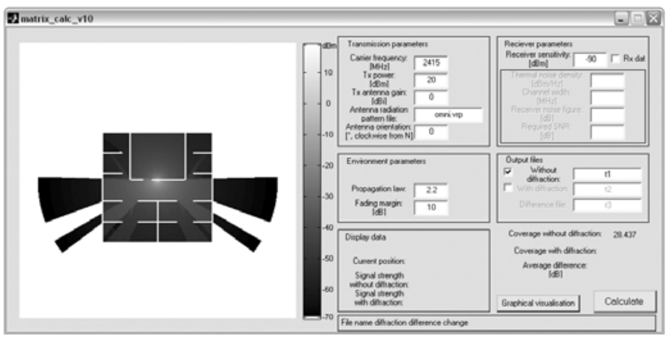


Figure 2 – Graphical user interface showing calculation results on the left and parameter entry fields on the right

3. MEASUREMENT SETUP

Several measurement series were done to determine the necessary environment and calculation parameters and to validate the propagation model. A wireless local area network (802.11b standard) was used in measurements as the most likely system for software application. The limited range allows measurements over the whole coverage area with relatively good resolution. Measurements were done using a single WLAN Access Point A11d (obtained from Ericsson) operating on the 5th channel at 2.433 GHz with 18 dBm output power. Two dipole antennas were used for transmission and the access point was placed at 1.5 m height on a styrofoam platform (fig.3).

A laptop computer with a wireless PCIMCIA card with an integrated antenna is used for signal strength and noise measurements (fig.4). The laptop is placed at 0.9 m height on a wheel cart for easier transportation and consistency of measurements. Laptop and wireless card with an integrated antenna are used to best simulate real working conditions.

For each point a series of measurement are done over a period of 10 to 20 seconds using a software package obtained from the manufacturer (fig.5). The results are saved and processed using a software created at Faculty of Electrical Engineering and Computing, and only mean values for each point are considered. This is done to counter the effects of fading as much as possible as fading reduces the reliability of measurements (as much as 10 dB to 30 dB drops in signal strength have been observed due to fading).

Figure 3 – Measurement setup – transmitter

Figure 4 – Measurement setup – receiver

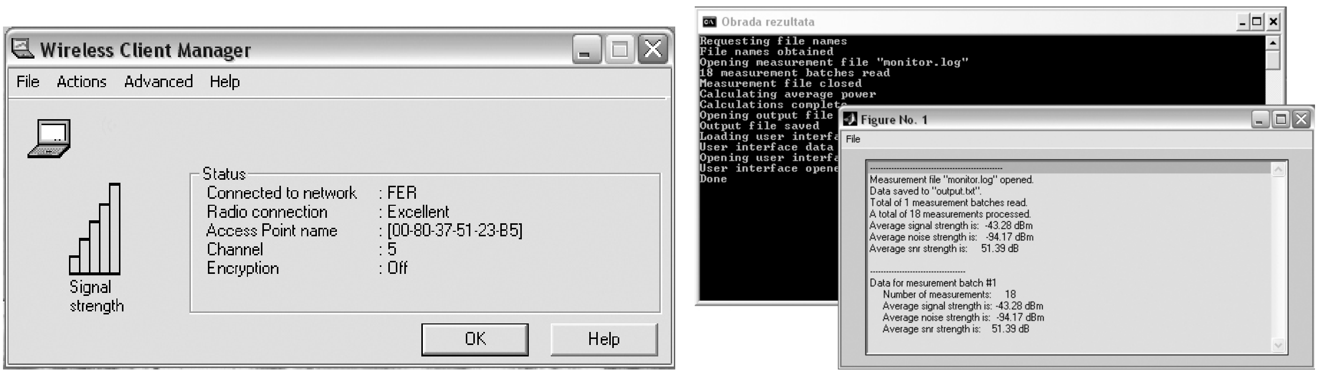


Figure 5 – Software used for measurements: (a) Wireless Client Manager and Site Monitor; (b) Software developed in MATLAB for measurement processing

4. MEASUREMENTS AND CALCULATION RESULTS

Measurements were done on 12th and 13th floor of Faculty of Electrical Engineering and Computing in Zagreb (fig.6). Used transmission and reflection loss values for objects are given in table 1. The environment mainly consists of concrete walls and wooden doors, with four elevators and large glass windows on outside walls. It counts a total of thirteen offices four large classrooms, one kitchen, two toilettes, one entry hallway, and one main corridor. The whole area is 15 m wide and 52 m long, and the used resolution was 0.25 m.

A number of key points and several routes were measured to accumulate sufficient amount of data for model validation. Measurements for two of these routes (classroom and corridor) and several points are shown on fig.7. Calculation results for the whole environment are shown on fig.8. The measurements confirmed the calculated results fairly well as far as coverage was concerned. Border areas where the measured signal strength became insufficient for communication coincide with the same calculated areas.

The model was calibrated using measurements from the classroom where access point was placed. These measurements and accompanying calculation results are shown on fig.9. The model parameters were set to follow these measurements as best as possible, and a comparison was made for the main corridor (fig.10). The standard deviation between measured points and neighboring calculated points in the corridor is 3.5 dB, showing a good correlation between measurements and calculations.

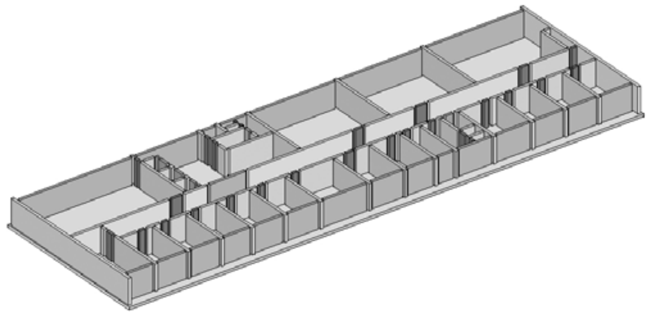


Figure 6 – Computer model of the 12th floor of FER building in Zagreb used for calculations of signal strength

Table 1 – Transmission and reflection losses for used objects

	Transmission losses	Reflection losses
Concrete walls	16	6
Windows	6	15
Doors	3	20
Elevator doors	80	1

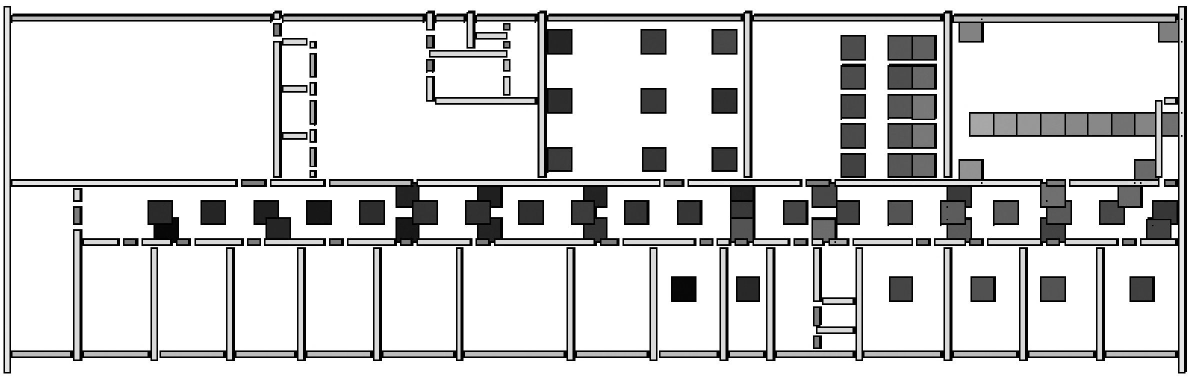
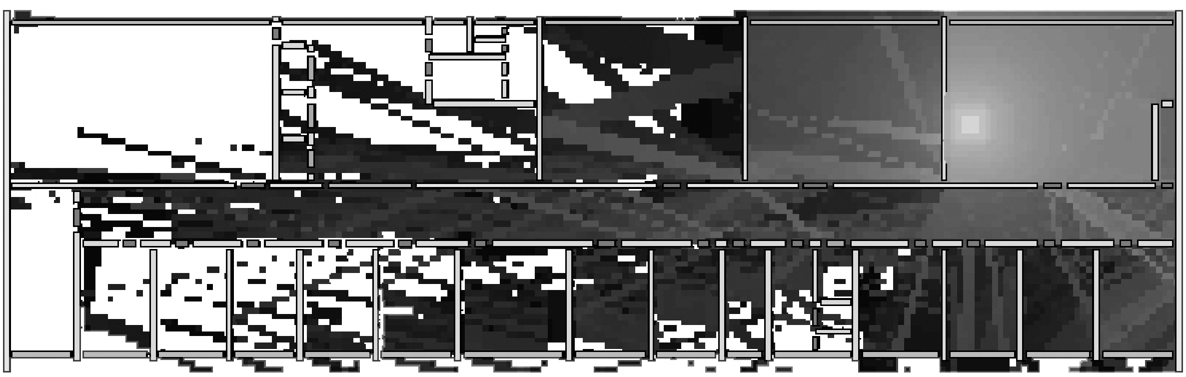


Figure 7 – Measurement results: P_{Tx} = 18 dBm, G_{Tx} = 2 dBi, f = 2.433 GHz



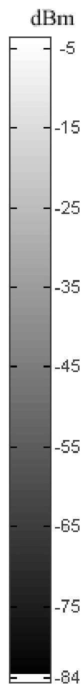


Figure 8 – Calculation results: P_{Tx} = 18 dBm, G_{Tx} = 2 dBi, f = 2.433 GHz, R = 2, fading margin = 10 dB

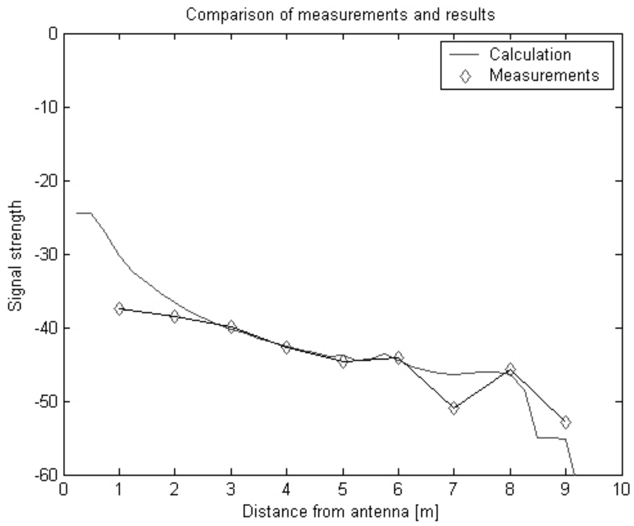


Figure 9 – Comparison of measurements and calculation within the room containing the access point. Measurements were done at every meter from the access point and used to set the model parameters. Standard deviation is 4.2 dB.

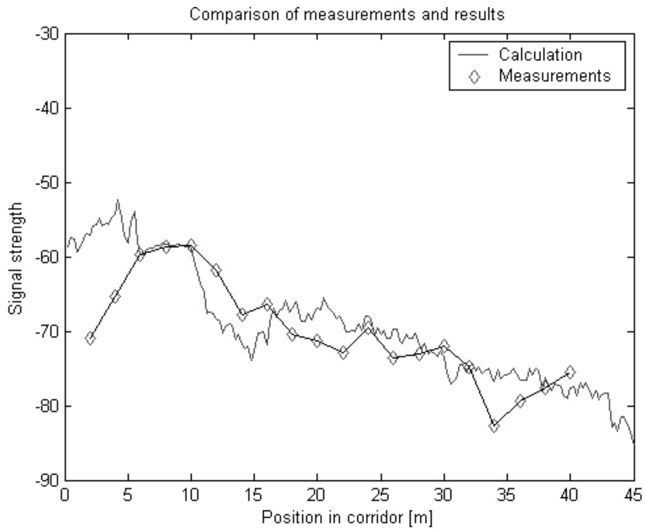


Figure 10 – Comparison of calculated and measured signal strength within the main corridor. Standard deviation between measurements and mean value of nearest calculated points is 3.5 dB.

5. CONCLUSION

This paper presented software developed in MATLAB for propagation prediction using a fast and accurate calculation method based on beam tracing. Accuracy of the used model is the same as for the ray-tracing models, and even better at larger distances from the transmitter. The main advantage over standard prediction methods is the simultaneous calculation of signal strength for the whole area, enabling the user to visualize the signal distribution for the whole map.

This different approach allows for faster calculation times in environments with relatively smaller number of obstacles. It is ideal for network planning purposes where not all information on the environment is available and results are needed for large areas. The calculation results shown in fig.8. contain signal strength information for 160.801 map points and took 513 seconds (more than 300 points per second) on a Pentium4 1.8 GHz computer. The software is therefore well suited for indoor network planning, and its results can easily be verified by practical measurements.

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