Development of a Wireless Communications Planning Tool for Optimizing Indoor Coverage Areas

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ABSTRACT

In this paper we present some preliminary results on the subject of indoor wireless communications planning by using computer simulation of signal propagation. The goal of this simulation is to obtain an overview of the received signal strength throughout the indoor environment and then try to optimize the coverage by moving the antenna properly. The optimization is considered as a procedure of moving signal "blind spots" according to a non-standard pattern that obeys custom needs, related to specific parameters of the environment (e.g. furniture).

I. INTRODUCTION

Modern trends in digital communications are focusing on ways and means by which indoor wireless services will evolve even more and overcome difficulties related to signal propagation inside buildings and dense office environments.

In such places, electromagnetic wave propagation suffers from deep fading, caused by multiple reflections from the room walls. The effect of fading is large variations in the received signal strength along a distance of only a few wavelengths long. The statistical properties of both fast and slow fading are well described in bibliography by Rayleigh and Rician probability functions and therefore we will not discuss them in this paper. [1-3]

The major cause of multipath fading is the vectorial addition of all incoming EM wave rays at the receiving point. These rays traveled different distances and some of them have been subjected to a single or multiple wall reflections, resulting to a total number of wave rays that have different phase arguments. When added at the receiving point, these vectors may (or not) cancel out, in respect with each other's phase. This results in deep signal variations when the receiver moves around the room.

A similar effect is observed when we monitor the received signal strength at a fixed point in the room, while changing the signal's frequency (for a CW signal propagation). This effect is often called frequency dispersion of the signal. Even though the receiver might suffer from a deep fade at a certain position and frequency, this does not mean that adjacent frequencies suffer as well. We can record such signal variations versus frequency at some points of the indoor environment. [4]

An example of this behavior is well illustrated in **Figure 1**, where the received signal is plotted versus frequency. This measurement was taken in an empty meeting room using a spectrum analyzer, a frequency generator feeding a TX antenna while sweeping the DECT band (1880-1900MHz) and a dipole antenna at the receiving point (RX antenna is not moving).

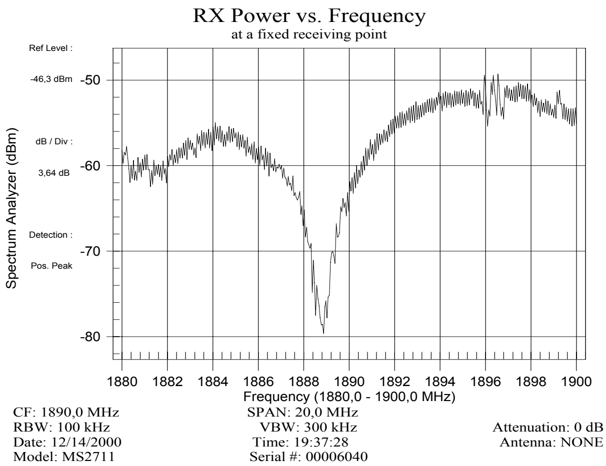


Figure 1. *Large signal variations versus frequency at a fixed receiving point in the room (blind spot).*

II. PROPAGATION SIMULATION

In real conditions like these, we are currently in the process of developing a software tool for visualizing the indoors-received signal strength and then marking the positions in the room where large signal variations are observed. We characterize these points as "blind spots" in the room.

By default, we consider these blind spots as points in the room in which the receiver probably might have a problem in communication and thus quite possibly will attempt a handover.

A. Simulation Scenario and Parameters

In this first stage of development, our software simulates signal propagation in a room according to a scenario that has many parameters. The parametric nature of the simulation program is one of our primary goals in the development process. The user has the ability to choose from many different views of graphic results.

The main parameters, being used to compute and simulate the indoor propagation, are a) wall materials, b) antenna position and c) signal frequency. Specifically, the scenario determines the following rules for the simulation:

- Rectangular room with variable dimensions.
- TX/RX antennas are at the same height and both are $\lambda/2$ dipoles.
- Near field effects are neglected.
- A maximum of 3 wall reflections are considered without taking into account ceiling or floor reflections.
- Wall materials are considered without losses.
- Scattering effects caused by sharp edges or discontinuities in the walls are neglected.

The problem of simulating the wave propagation has been simplified with these assumptions. Calculations take place in a single plane (2D problem) at points of a predefined grid (also variable). The received signal strength (power) is calculated by using the following formula:

$$P = \frac{1}{2}\mathrm{Re}\left(\overline{E} \times \overline{H}\right) \qquad (1)$$

where the vectors for the electric and magnetic fields are given by the following equations:

$$E_{\vartheta} = \frac{j\eta_o I_o e^{-j\beta r} \cos\left(\frac{\pi}{2}\cos\vartheta\right)}{2\pi r \sin\vartheta} \qquad (2)$$

$$H_{\varphi} = \frac{jI_o e^{-j\beta r} \cos\left(\frac{\pi}{2}\cos\vartheta\right)}{2\pi r \sin\vartheta} \qquad (3)$$

The total power at the receiving point is calculated by (1) but $\vec{E}$ and $\vec{H}$ vectors consist of all incoming rays at the point of interest (vectorial addition). The reflected components are calculated by using the reflection coefficients for electromagnetic reflection in a medium without losses. [5]

The dimensions of the room were initially taken equal to 10×5m. The frequencies selected for these preliminary results were in the official DECT band (1880-1900MHz). The wavelength in this band is about 15cm. The calculation grid points were selected to differ by 5cm. This is quite right for acquiring satisfactory results, since the Nyquist sampling theorem forces sampling at least in every $\lambda/2$ ($\approx$7cm for DECT).

B. Propagation Results

Now we are ready to present our first results of this simulation scenario. At the following figures the receiving power is illustrated versus (x,y), which are the coordinates of the grid plane. Note the large signal variations which are obvious in all figures. In **Figures 2** and **3** we plotted the simulation results while changing wall parameters (dielectric properties of the walls) [6]. In **Figures 4, 5** and **6** we changed the antenna position gradually towards the metal wall and we observed the changes in the signal pattern across the room.

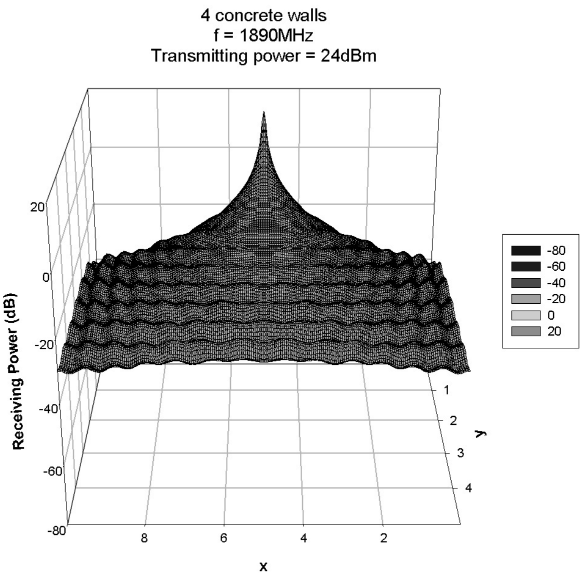


Figure 2. *Antenna positioned at (5,0). The room has 4 concrete walls without losses.*

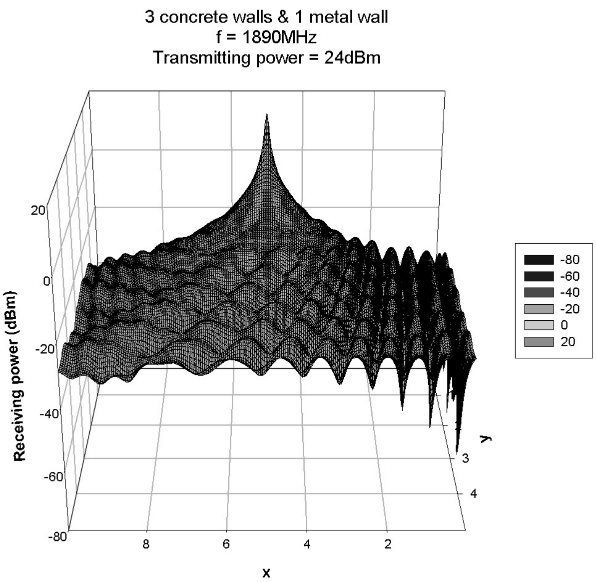


Figure 3. *Antenna positioned at (5,0). The room has 3 concrete walls and 1 metal wall (right).*

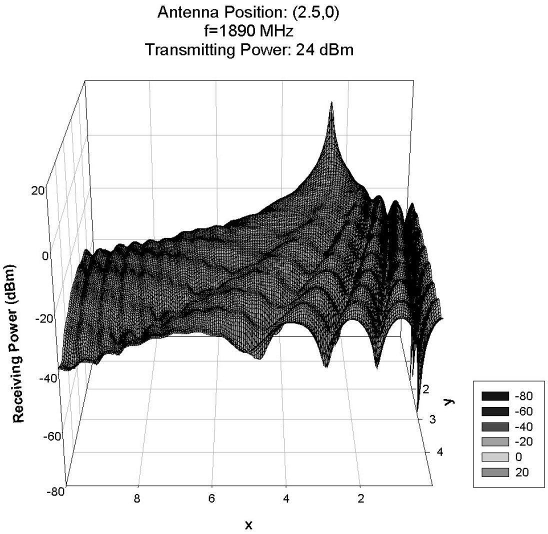


Figure 4. *Antenna positioned at (2.5,0). The room has 3 concrete walls and 1 metal wall (right).*

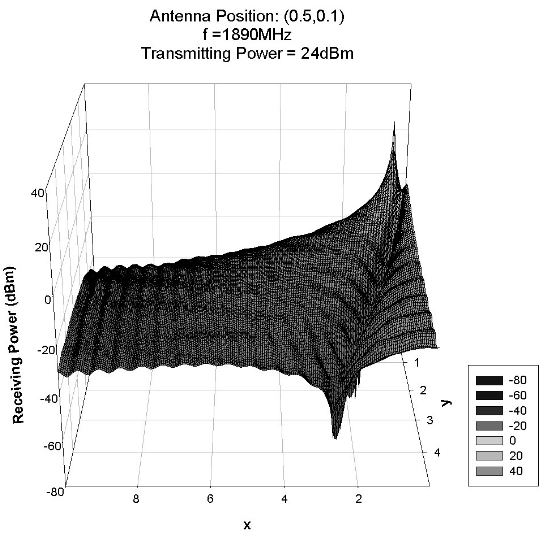


Figure 5. *Antenna positioned at (0.5,0.1). The room has 3 concrete walls and 1 metal wall (right).*

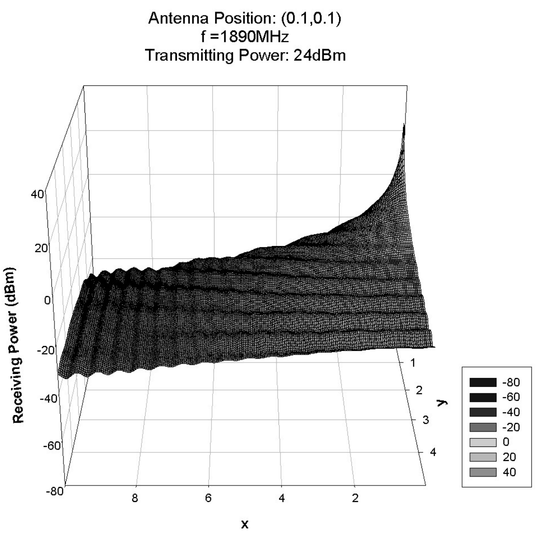


Figure 6. *Antenna positioned at (0.1,0.1). The room has 3 concrete walls and 1 metal wall (right).*

III. OPTIMAL ANTENNA POSITIONING

A. Determination of "Blind Spots"

The 2nd part of our results concerns the determination of the positions of the "blind spots". **Figure 7** shows a comparison between the results of a real measurement that describes the "blind spot" and a random result of the simulation program. The similarity of the two curves is obvious.

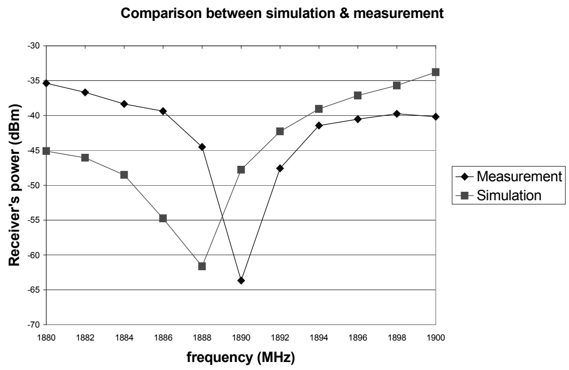


Figure 7. *Comparison between simulation results and real measurement data.*

The positions of these "spots" that are shown at the following diagrams are such that there is at least a 20dB difference of the calculated power in the DECT frequency range (1880-1900MHz). The first part of the simulation's results deals with determining the relationship between the materials of the room and the appearance of a "blind spot", while the second part deals with the potentiality to control their position in the room.

Figures 8 and **9** show the positions of "blind spots" if there is one highly reflective wall and two highly reflective walls respectively. Judging from these results it is obvious that the appearance of such a "spot" strongly depends on the existence of the reflective surface. Practically, the reflective wall, as it is being considered in the simulation, is responsible for the existence of a ray that is comparable in magnitude to the direct ray but shows such a phase variation that they cancel out. Therefore, the signal becomes unstable and comparable to the less powerful rays that, when added as vectors, either amplify or attenuate the overall signal depending on the wavelength (frequency).

At this point it should be reminded that in this scenario the transmitting antenna is inside the room, retaining line-of-sight conditions, which is not the usual case for most indoor applications. Therefore, in an effort to generalize our conclusion from the previous paragraph, we could say that the appearance of a "blind spot" is straightly related to the existence of comparable rays. If, for example, we consider a more complex scenario according to which the simulation takes place in a building that is characterized by several materials, different rays are subjected to different variations. Therefore a direct ray between the transmitter and the receiver might suffer from severe attenuation compared to one that covered greater distance; these two could form a comparable pair, regardless of the reflective properties of the materials involved. Concluding, in order to take into account all possible cases that could result to a "blind spot" we consider necessary the creation of a very accurate software.

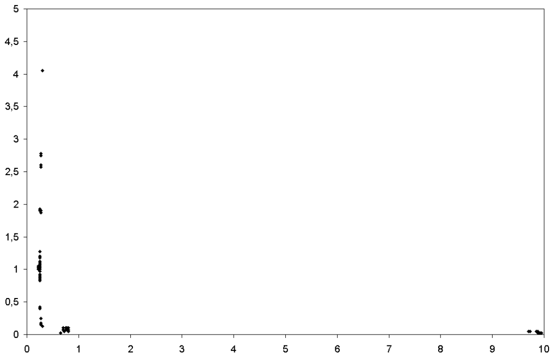


Figure 8. *The reflective wall is at the left side of the room. The transmitter is positioned at (5,0).*

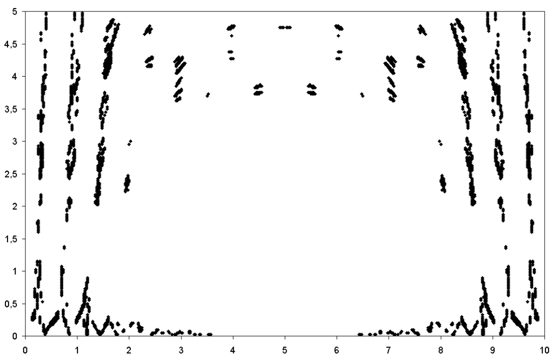
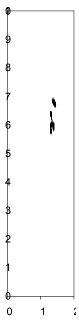


Figure 9. *Two reflective walls on the left and right side of the room. The transmitter is positioned at (5,0).*



We could also say that those spots are limited to an area close to the room's walls. This however would not be the case in a more accurate scenario, as described in the preceding paragraph, or inside a corridor of a building, as shown in **Figure 10**, where the "spots" appear in the middle of the area.

Figure 10. *Antenna is positioned at (1,0).*

Another interesting point would be to examine the effect of those "blind spots" in the quality of services in a communications' system and, if possible, to find a measure to describe that effect. We could suppose that if a subscriber appears in such a "spot" he would be subjected not only to interference but also to amplitude and phase distortion. Therefore, in such an occasion, we could suppose some kind of information loss. If we could calculate the number of "blind spots" in any indoor environment, we could then produce a ratio of the "blind spots" to the total grid points calculated. We could then consider a percentage of this ratio as lost information and add this result to the calculation of Quality of Service.

B. Optimization

Furthermore, another issue would be to try to control the position of those "blind spots". This could be done either by moving the antenna inside the room (optimal antenna positioning), thus leading the unwanted spots above furniture or close to walls and corners, or using an appropriate antenna; we could use the antenna's pattern in order to direct the signal towards the desirable direction. Of course in indoor environments we consider essential the use of a diversity technique, as a measure against this phenomenon [7]. This would also be a matter that is worthy of our deeper investigation. In the next six figures we observe the movement of the "blind spots" as we move the transmitter inside the room.

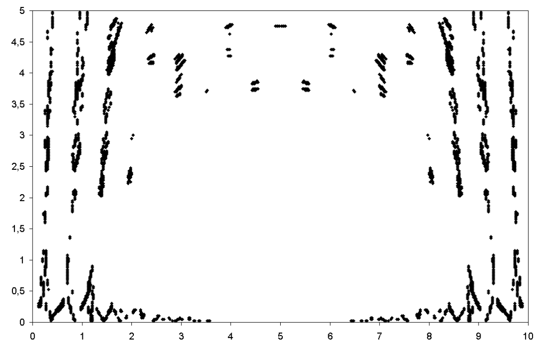


Figure 11. *The transmitter is positioned at (5,0).*

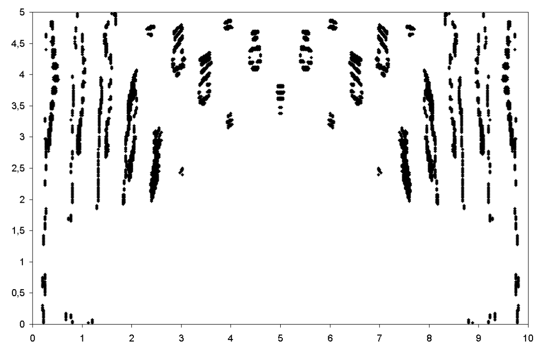


Figure 12. *The transmitter is positioned at (5,0.5).*

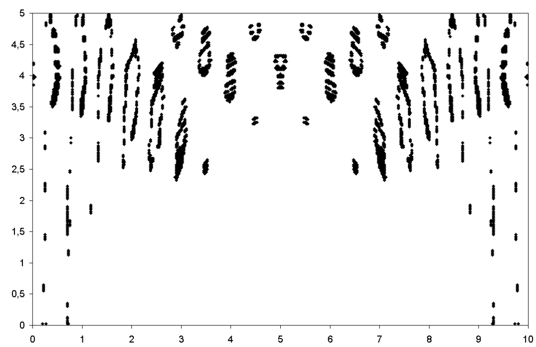


Figure 13. *The transmitter is positioned at (5,1).*

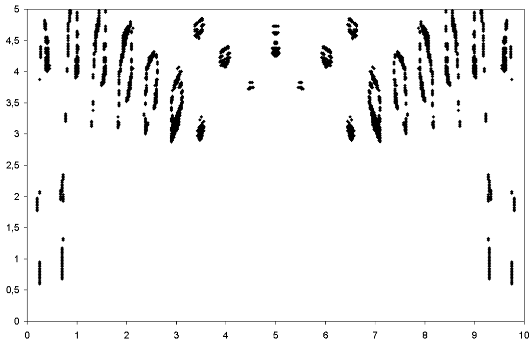


Figure 14. *The transmitter is positioned at (5,1.5).*

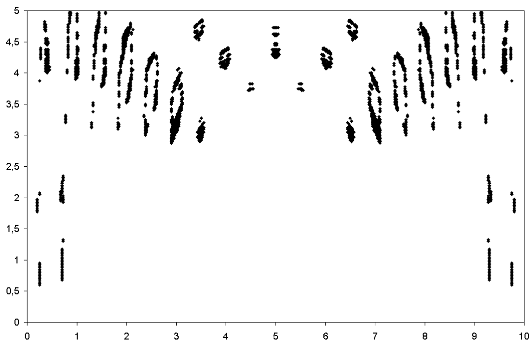


Figure 15. *The transmitter is positioned at (5,2).*

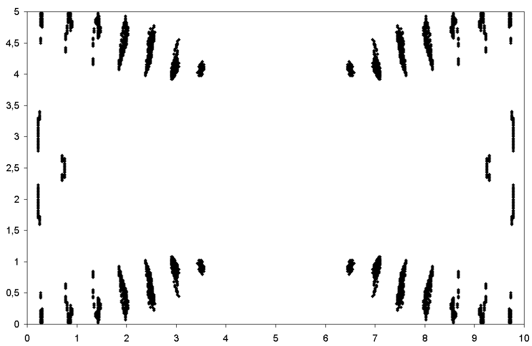


Figure 16. *The transmitter is positioned at (5,2.5).*

IV. CONCLUSIONS

The study that was presented in this paper shows that it is possible to create a parametric software tool in order to predict with satisfactory precision the propagation of EM waves in an indoor environment and effectively install and optimize the RF system, according to the local environment. The program should be developed towards the following directions:

- All materials' characteristics should be carefully considered.
- The antenna should also be able to be positioned anywhere in the building under examination.
- We should take into account a considerable number of rays from all directions (3D problem).
- The calculations should carefully consider all the characteristics of signal propagation (diffraction, transmission through walls).
- The radiation pattern of the transmitting antenna should also be considered and the program should be flexible with handling any antenna pattern.

We believe that such kind of software would be very useful in the current rapid development of indoor wireless applications.

Preliminary results (that were presented here) show that there's a lot more in this area beyond the point of just predicting signal propagation. We believe that smart algorithms can be developed that will optimize the final position of the antenna in a complex indoor environment. The best selection of the antenna type and radiation pattern is also a parameter that can be easily tested, as presented earlier.

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