STUDY OF HUMAN BODY EFFECT
ON WIRELESS INDOOR COMMUNICATION

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ABSTRACT

The knowledge on the different propagation mechanisms of wireless data transition in confined environments has become crucial in the design of reliable and robust communication systems. The present work presents signal strength measurements, analysis, and prediction models for indoors, outdoors and near human body scenarios. The measurements were conducted by using a continuous wave (CW) transmitter and receiver antenna pair at 0.5GHz. The measured data results were compared against multi-path model prediction. The path loss estimated from the multi-path model has good agreement with the measured data.

INTRODUCTION

The performance of the wireless systems in the indoor environment is significantly influenced by multipath mechanisms such as multiple reflections, diffraction, and scattering. Due to the large path loss and diffraction loss, human body shadowing (HBS) has a huge impact on wireless communication and requires intensive research (Chen *et al*., 2016).

The path loses for outdoor and indoor environments with the presence of objects were studied over the last decade (Huang *et al*., 2005; Saito *et al*., 2012; Deng *et al*., 2016; Synthia, 2016; Zhou, 2017). However these works do not fully reveal the effect of human body presence on the receiving signal.

In the current work, outdoor and indoor measurements were conducted with and without human body presence. The measurements for all cases were taken at 0.5 GHz by using a pair of antennas. The measurements were compered to multi-path ray models taking into account the refraction and diffraction effects.

1.1. THE MODEL

Electromagnetic waves propagate through environments where they are reflected, scattered and diffracted by walls and objects. The Maxwell's equations provide the comprehensive description for the propagation phenomena.

The most common models use ray-tracing techniques. These techniques approximate the propagation of electromagnetic waves by representing the wavefronts as simple particles: the model determines the reflection and refraction effects on the wavefront (Rappaport, 1996; Goldsmith, 2005).

1.2. PATH LOSS

The *linear path loss* of the channel is defined as the ratio of transmit power to receive power $\left(P_t/P_r\right)$, and the *path loss* of the channel as the dB value of the linear path loss $\left(P_t/P_r\right)[\mathrm{dB}]=10\log_{10}\left(P_t/P_r\right)$. The power ratio and the field ratio are related by

$$\frac{P_r}{P_t}=\left|\frac{E_r}{E_t}\right|^2 \tag{1}$$

1.3. FREE-SPACE PATH LOSS

Consider a signal transmitted through free space to a receiver. Assume there are no obstructions between the transmitter and receiver and the signal propagates along a straight line between the two: *line-of-sight* (LOS).

Free-space path loss obtained by the Friis free space equation

$$\left(\frac{E_r}{E_t}\right)_{LoS}=\left(\frac{\lambda}{4\pi}\right)\frac{\sqrt{G_tG_r}}{L}e^{-ikL} \tag{2}$$

where L is the transmitter- receiver distance, λ is the signal wavelength ($\lambda=c/f$), G_t and G_r are the transmit and receive antennas gain f is the frequency c is the speed of light (3×10^8m/s) and $k=2\pi/\lambda$.

According to Friis free space path loss formula, the higher radio frequency is, the greater path loss is. Furthermore, the received signal power falls off inversely proportional to the square of the distance L between the transmit and receive antennas.

1.4. TWO-RAY MODEL

The simplest ray-tracing model is the two-ray model, which accurately describes signal propagation when there is one direct path between the transmitter and receiver and one reflected path.

$$\frac{E_r}{E_t}=\left(\frac{\lambda}{4\pi}\right)\left[\frac{\sqrt{G_tG_r}}{L}e^{-ikL}+\frac{\sqrt{G_tG_r}}{L_{ref}}\rho e^{-ikL_{ref}}\right] \tag{3}$$

where the reflected ray path $L_\mathrm{ref}=L'+L''$ (Figure 1). The ground reflection coefficient is given by

$$\rho=\frac{\sin(\theta)-Z}{\sin(\theta)+Z} \tag{4}$$

where

$$Z = \begin{cases} \sqrt{\varepsilon_r - \cos^2(\theta)} \big/ \varepsilon_r & \text{Polarization: Vertical} \\ \sqrt{\varepsilon_r - \cos^2(\theta)} & \text{Polarization: Horizontal} \end{cases} \tag{5}$$

and ε_r is the dielectric constant of the ground and θ is the refraction angle.

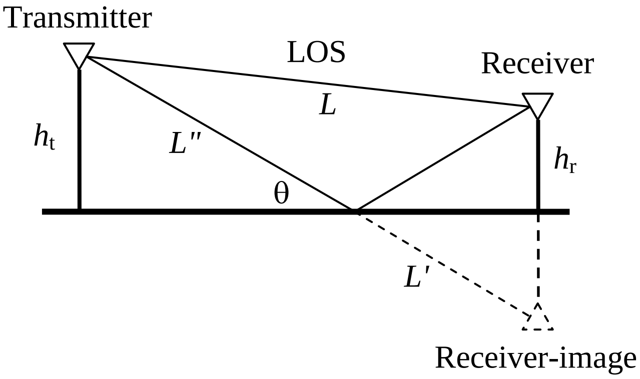

Figure 1: Two-Ray Model and the image method

1.5. MULTI-PATH RAY TRACING METHOD

The electromagnetic signal propagation in the indoor is most commonly and accurately characterized by the ray tracing method. The principle of ray tracing using image method, involves finding the exact number of reflected paths to the receiver using transmitter images

Based on the ray-tracing method, the electric field in a hollow tunnel or room can be represented by a summation of the electric fields from the two-dimensional images of the source in the excitation plane (Zhou, et al. 2015). In the current work a modified ray-tracing model for indoor propagation is developed and tested.

1.6. PROPAGATION NEAR OBJECTS

The presence of an object or an obstacle in the propagation space causes to combined effects of refraction diffraction and scattering. The last two are significant in the case of "shadowing". The propagation model for the LOS and reflected paths was outlined in the previous section.

Diffraction occurs when the transmitted signal “bends around” an object in its path to the receiver, as shown in Figure 2. The knife edge diffraction (KED) model is commonly used in ray tracing simulations due to its simplicity and accuracy for diffraction loss prediction for many geometries. However the KED model can only be used for sharp knife edges, and does not account for the radius of curvature of an obstacle. A creeping wave is the wave that is diffracted around the surface of a rounded obstacle such as a circular cylinder (Deng, 2016).

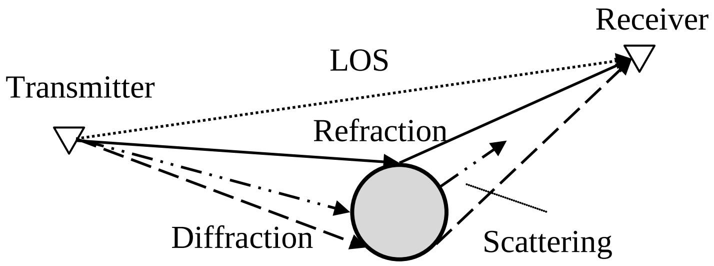

Figure 2: Ray-tracing illustration near a circular cylinder:
Line of site, retraction diffraction and scattering

1.7. THE CURRENT MODEL

The current model calculates the received signal in indoor space with the presence of a cylindrical object. The received signal is determined from the superposition of the components due to the multiple rays: line of site, refraction from the walls refraction from the object and diffraction from the object.

2. EXPERIMENTAL SETUP

The measurements were conducted indoors and outdoors by using a continuous wave (CW) SDR (Software Defined Radio) made by Analog-Devices at frequency of 500 MHz (λ=1.67m). The signal strength was measured as a function of the transmitter-receiver distance and with the presence of a human in various locations.

Figure 3: Room and tunnel experiment set-up

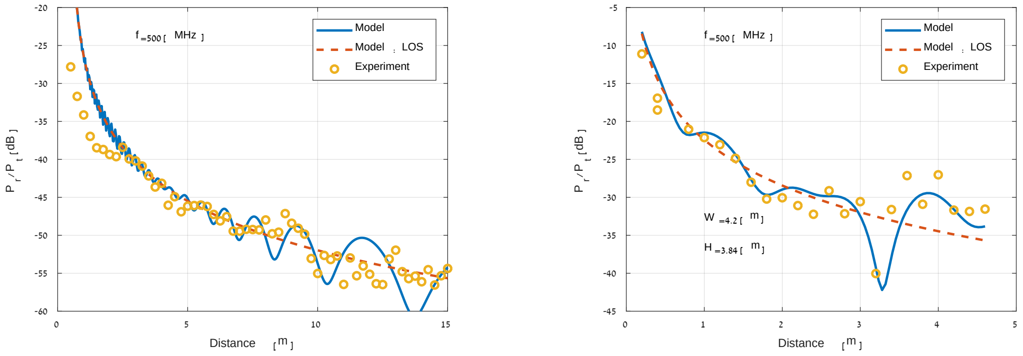

Figure 4: Outdoor and Indoor: Model and experiment

3. RESULTS

The signal strength of wireless communication in outdoor and indoor environments and with the presence of human body was studied theoretically and experimentally.

The 2-ray and multi-ray models for outdoor and indoor cases were tasted for various transmitter-receiver distances (Figure 4). Figure 4a presents the experimental results and 2-ray model predictions for outdoor environment and Figure 4b presents the experimental results and multi-path model predictions for indoor environment. In both cases is seems to be good model predictions.

The effect of human body in outdoor environment was tested experimentally. The signal strength was measured for various distance of the body relative to the line of site (Figure 5). The retraction effect when the body is close to the line of site and the shadowing effect when the body is in the path of the line of site are clearly seen.

The effect of cylindrical object in outdoor environment was studied theoretically. The signal strength was modeled for various positions of the object on the room diagonal (object in motion) (Figure 6). The shadowing effect when the body is in the path of the line of site and on the refracted rays are clearly seen.

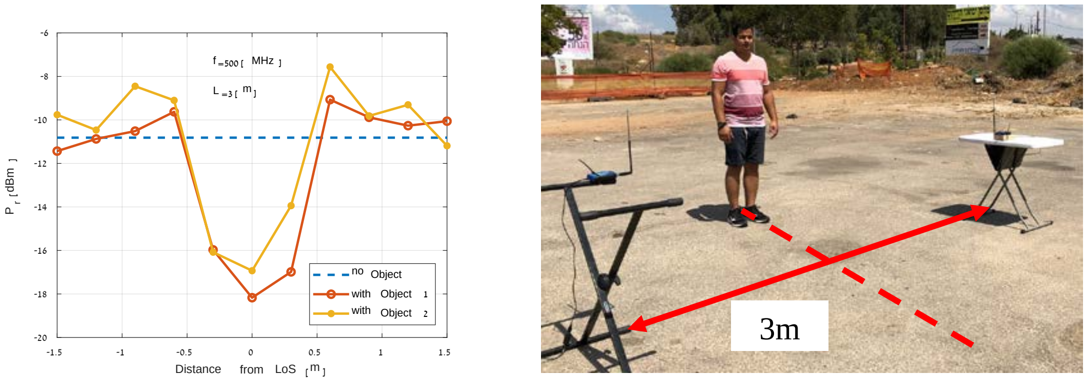

Figure 5: Human body effect: Open space experiment

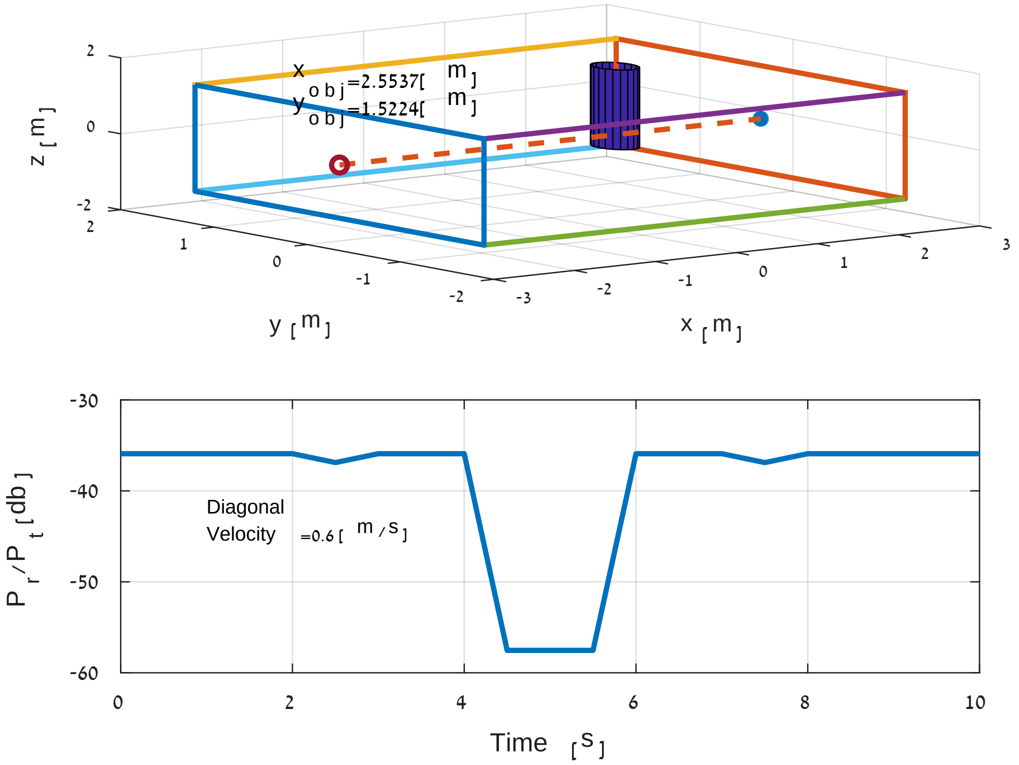

Figure 6: Human body effect: Indoor space experiment with cylindrical object on the room diagonal (object in motion)

4. CONCLUSIONS

The performance of the wireless systems is significantly influenced by multiple reflections in addition to diffraction and scattering propagation effects. The current work performs investigations on the deterministic ray tracing of the wireless signals at 0.5GHz frequency in the outdoor and indoor scenarios and with the presence of a human body.

Received signal measurements were collected at various distances. Ray tracing model by image method is used to estimate the path loss starting from the basic two ray model and extending it to multi-path rays model. The prediction results from these models were compared with the measured data. The path loss estimated from the multi path model has good agreement with the measured data.

5. REFERENCES

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