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# Radiowave Propagation in Picocellular Environment using 2.5D Ray Tracing Technique

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***Abstract*—**This paper presents a ray tracing simulation technique for characterize the radiowave propagation inside building. The implementation of an algorithm capable of enumerating a large number of propagation paths in interactive time for the special case of 2.5D. The effective dielectric constants of the building structure in the simulations are indicated. The study describes an efficient 2.5D model of ray tracing algorithm were compared with 3D model. The result of the first investigations is that the environment of the indoor wave significantly changes as we change the electric parameters of material constructions. A detailed analysis of the dependence of the indoor wave on the wideband characteristics of the channel: root mean square (RMS) delay spread characteristics and Mean excess delay, is also investigated.

***Keywords*—**Picrocellular, Propagation, Ray tracing



## I. INTRODUCTION

DETERMINISTIC wave propagation models are growing their importance day after day, becoming fundamental for the characterization of indoor propagation. Moreover high simulation accuracy often requires a huge computation time that sorely tries CPU's strength and speed. In most cases hardware empowering is not enough to reduce computer simulation time, which can vary from minutes to weeks [1].

Therefore it is necessary to perform a deep optimization on the algorithm and simplifying assumptions on the propagation models are often unavoidable to increase performances. The visible window image model of ray tracing was performed to analysis and simulated the propagation characteristics of the picocellular propagation channel environment. The focal point of the model to extend the 2D of the classical image method algorithm to the 2.5D in order to give more precision, and to reduce the computation time execution than 3D ray path algorithm. The advantage of that to make algorithm as 3D in accuracy and faster as 2D, and by this condition the optimization is realized.The propagation of waves through such structures is a complex process that cannot be rigorously analyzed within a general-purpose program. Therefore, simple models of these structures are necessary to calculate transmitted, reflected, and diffracted fields by means of closed form expressions. By using ray-tracing technique, the ray interactions with the propagation environment are tracked for horizontal polarization and vertical polarization by taking into account the electromagnetic properties of construction materials.

## II. DESCRIPTION OF THE ALGORITHM

Propagation in 2.5D refers to a hybrid version of 3D propagation. In this hybrid, we consider a medium in which the wave speed is only a function of two variables, say (x, z), and then evaluate the 3D waves only in the (x, z) plane. The special case of 3D propagation in-plane in a medium with 2D variation leads to the name 2.5D.

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Further, for numerical tests, 2.5D provides a near-3D test with all calculations carried out in 2D.

In author's algorithm, I have extended the 2D of the classical image method algorithm to the 2.5D in order to give more precision, and to reduce the computation time execution than 3D ray path algorithm. The advantage of that to make algorithm as 3D in accuracy and faster as 2D, and by this condition the optimization is realized. My algorithm was originally conceptualized from [2], were realized by ray launching method for outdoors environment, and scanning the ray path in the 2.5D, which means that when the ray path reflected from ceiling, and / or from ground can be uniquely represented by 3D coordinates: x, y, and z, and all reflections from the walls represented by 2D coordinates: x and y. Only one order ray reflection from the ceiling and one order ray reflection from ground are assumed, as shown in Fig. 1, which clearly show the 2.5D path emitted from Tx to the Rx and presented by black ray color.

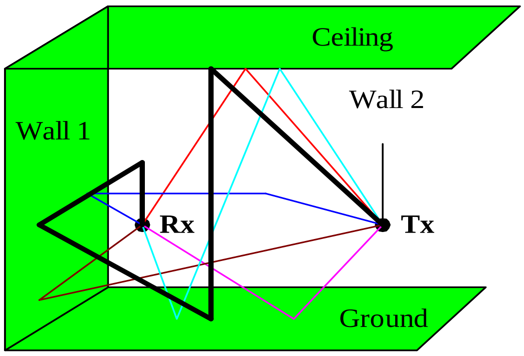

Fig. 1 Rays in 2.5 dimensional space

The idea of the visibility algorithm as shown in Fig. 2. is taken from [3]. The process, is scanning with reference point, the transmitter position *Tx* is performed in order to compute all visible elements in illumination area of the environment. Iterates over the sorted list of end points and maintains a data structure that contains the list of segments being currently intersected by the scanning ray paths as indicating in Fig. 2.

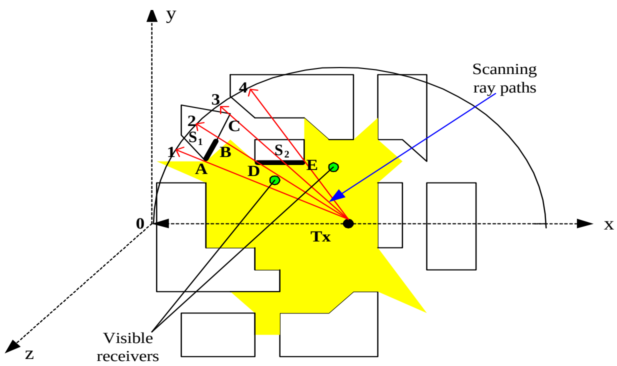

Fig. 2 Scanning visible algorithm

Each time a left end point of a segment is found the corresponding segment is inserted into the data structure. If the segment is closer than any other segment currently held, this segment determines the visible border. In Fig 2. two linear segments ($S_1$ *and* $S_2$), representing walls are shown.

When a scanning is made, the first segment end found is point *A* corresponding to scan ray path 1. Segment $S_1$ defined by its end points *A* and *C*, then the $S_1$ partially visible and thus partially stored in the visibility list indicating its visibility section (*A*-*B*). At scan ray path 2, segment $S_2$ begins to be visible (point *D*), and the scanning process for the segment 2 will be end at point *E*, where ray path 4 ends.

Then the segment 2 is deemed to be completely visible and it is stored in a visibility list, where the visibility list is the set that contains the transmitter, all images sources that generated directly by the transmitter or other image or / and all reflection and diffraction sources. The partial segment $S_1$ (*B*-*C*) becomes invisible, were ray path 2 *and* ray path 3 are swept, consequence of that the partial of the segments are not lie in the visible windows of image process, so instead of scanning and sweep a whole rays, were emitted from *Tx* to the *Rx* at illumination area (visible area), the environment surfaces are divided to the windows, and it is enough to scan fragments (windows), of that visible area to follow up the ray path and check if it's passing through that window, then the image of that path considered be valid and saved in the visible list [4].

## III. Simulation Results

The algorithm is implemented on a Window XP, and the tracer written in C++ Builder language. The RayProp Simulator is created and supported by parallel optimization for implement of the algorithm.

The model was applied to the corridor environment and compared with measured results. The schematic of environment dimension is (30m long, 2.6m wide, 2.6m height), and the transmitter Tx and receiver Rx are located as shown in Fig. 3, where the transmitter are stationary and the receiver are moved to many locations. The walls are made of concrete, which has dielectric constant ($\varepsilon = 7+j0.4$). Through the walls is partially covered with glass windows, which has dielectric constant ($\varepsilon = 6+j0.05$), as indicated in the Fig. 3.

There are many doors, made of wood, which has dielectric constant ($\varepsilon = 2.5+j0.03$). The simulations and the measurements were performed for a frequency of 1.9 GHz when a path arrives at a point, it has already gone through many reflections and transmissions.

The table I and table II, shows values for the mean excess delay ($\tau$), and RMS delay spread ($\sigma$) for each receiver locations for line of sight (LOS) and non line of sight (NLOS) situation respectively through the corridor.

By observation of the table I and table II, it can be explained by the fact that the corridor environment was complex, and any small variation in the position of the receiving antenna led to a substantial variation of the paths between transmitter and receiver and, consequently a noticeable change in the characteristic of propagation channel.

The average RMS delay spread of LOS ten receiver locations was 17.00ns for measured and 22.72ns for 2.5D simulation, while for 2D is 20.16ns and 24.24ns for 3D case. The average RMS delay spread for the same receiver locations but for NLOS, was 22.76ns, 20.57ns, and 24.38ns for 2.5D, 2D,and 3D simulated situation respectively, and 21.85ns for measured.

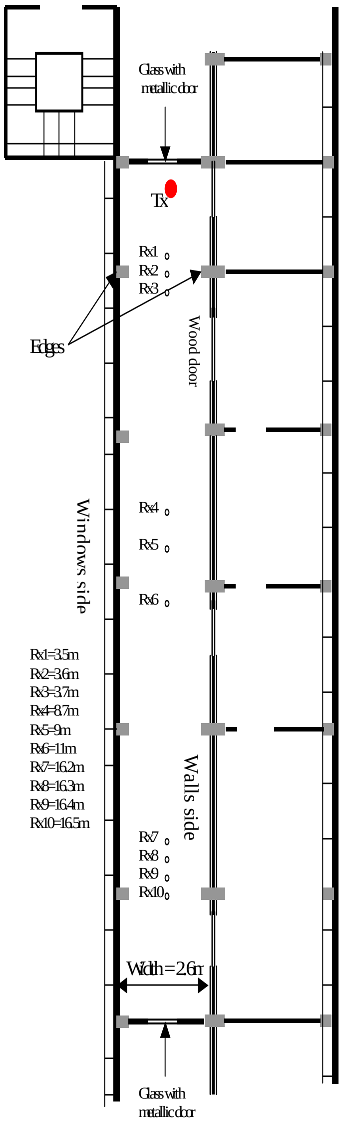


Fig. 3 Layout of Corridor environment

The values of RMS delay spread, which we got by our modeling for our environment inside building are consistent and agree with reported values of RMS delay spread between 20ns and 50ns for small size office buildings [5, 6]. A correlation study was performed for RMS delay spread with respect to the receiver displacement. The result has shown that the presence of a LOS path, the environment construction under consideration is the main contributory factors in determining the values of the temporal dispersion. As expected, the NLOS scenarios generally exhibit higher values of RMS delay spread.

TABLE I
RMS DELAY SPREAD AND MEAN EXCESS DELAY FOR TEN RECEIVER LOCATIONS THROUGH THE CORRIDOR FOR LOS CASE

| Location LOS at Corridor | Measured | | RayProp Simulation Optimization Mode | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | 2D | | 2.5D | | 3D | |
| | σ [ns] | τ [ns] | σ [ns] | τ [ns] | σ [ns] | τ [ns] | σ [ns] | τ [ns] |
| Rx1 (3.5m) | 18.18 | 17.30 | 16.33 | 12.57 | 21.82 | 14.55 | 24.70 | 16.14 |
| Rx2 (3.6m) | 21.28 | 17.74 | 17.40 | 13.75 | 23.19 | 16.09 | 26.04 | 17.80 |
| Rx3 (3.7m) | 14.72 | 14.70 | 17.63 | 14.00 | 23.48 | 16.39 | 26.40 | 18.17 |
| Rx4 (8.7m) | 13.11 | 32.92 | 17.05 | 29.58 | 20.50 | 31.22 | 22.15 | 32.56 |
| Rx5 (9m) | 17.80 | 28.73 | 18.92 | 30.98 | 22.05 | 32.55 | 23.48 | 33.99 |
| Rx6 (11m) | 9.23 | 36.19 | 21.56 | 40.22 | 26.20 | 42.23 | 27.36 | 43.69 |
| Rx7 (16.2m) | 18.43 | 52.70 | 22.88 | 58.24 | 22.65 | 58.74 | 23.30 | 59.45 |
| Rx8 (16.3m) | 18.03 | 56.39 | 22.36 | 58.02 | 22.15 | 58.92 | 22.98 | 59.82 |
| Rx9 (16.4m) | 19.28 | 61.90 | 23.18 | 58.25 | 22.23 | 60.05 | 22.72 | 60.55 |
| Rx10 (16.5m) | 20.03 | 61.38 | 24.27 | 58.74 | 22.90 | 61.17 | 23.29 | 61.67 |
| **AVERAGE** | **17.00** | **38.00** | **20.16** | **37.44** | **22.72** | **39.19** | **24.24** | **40.38** |

TABLE II
RMS DELAY SPREAD AND MEAN EXCESS DELAY FOR TEN RECEIVER LOCATIONS THROUGH THE CORRIDOR FOR NLOS CASE

| Location NLOS at Corridor | Measured | | RayProp Simulation Optimization Mode | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | 2D | | 2.5D | | 3D | |
| | σ [ns] | τ [ns] | σ [ns] | τ [ns] | σ [ns] | τ [ns] | σ [ns] | τ [ns] |
| Rx1 (3.5m) | 30.82 | 26.14 | 20.63 | 14.47 | 26.04 | 16.92 | 29.54 | 19.06 |
| Rx2 (3.6m) | 29.82 | 16.90 | 17.70 | 13.75 | 23.75 | 16.16 | 27.55 | 18.30 |
| Rx3 (3.7m) | 25.94 | 17.12 | 17.83 | 13.94 | 23.06 | 16.16 | 26.47 | 18.16 |
| Rx4 (8.7m) | 19.56 | 28.00 | 16.90 | 29.07 | 19.22 | 30.30 | 21.07 | 31.61 |
| Rx5 (9m) | 20.43 | 31.57 | 18.60 | 31.52 | 21.27 | 32.72 | 22.14 | 33.78 |
| Rx6 (11m) | 13.52 | 33.95 | 20.17 | 38.69 | 23.83 | 40.55 | 24.68 | 41.77 |
| Rx7 (16.2m) | 18.95 | 62.16 | 23.13 | 58.35 | 22.74 | 58.81 | 23.26 | 59.47 |
| Rx8 (16.3m) | 19.73 | 63.54 | 22.65 | 58.13 | 22.27 | 58.99 | 23.01 | 59.86 |
| Rx9 (16.4m) | 20.85 | 64.72 | 23.51 | 58.38 | 22.38 | 60.11 | 22.77 | 60.58 |
| Rx10 (16.5m) | 18.90 | 61.03 | 24.58 | 58.15 | 23.05 | 61.25 | 23.35 | 61.71 |
| **AVERAGE** | **21.85** | **40.51** | **20.57** | **37.45** | **22.76** | **39.20** | **24.38** | **40.43** |

We indicate that the qualitative comparisons of our ray tracing simulation give a good agreement results with real measurements. Interesting results to note from the values for mean excess delay are the relatively high values, as excepted for the Corridor receiver locations, because significant reflections arrive over a large time period.

The simulation results compared with real measurement values, due to Line-of-Sight (LOS) path and Non Line-of-Sight (NLOS), and presented in Fig.4 and Fig.5, respectively. for the Rx12 and Rx1 receiver positions inside room laboratory, were only five reflections are considered and produced by VWIM for 2.5D. From the Figs we can notice that there is a big coincidence between 2.5D and real measurements.

## IV. Conclusion

In this paper, the efficient algorithm, were implemented by RayProp software package simulator, and released in the corridor environment., the proposed model avoids the use of the usual time-consuming algorithms to determine the appropriate propagation paths. It therefore provides significant advantage in computational efficiency. Excellent agreements were observed with compared with real measurement results with our model for the same test site. The paper show to use 2.5D mode properly useful for both LOS and NLOS than using 2D and 3D mode.

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