# Evaluation of UWB System Coverage with the 2D Parflow Method

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## ABSTRACT

We present a fast, efficient and accurate approach for planning the Ultra Wide Band (UWB) system deployment using the 2-dimensional Parflow method [2]. The Parflow is based on the Lattice-Boltzmann method (LBM), which was initially developed for gas-kinetic representation of fluid flow and can be also used for modelling electromagnetic wave propagation [2] [6]. It is shown [14], [3] that the scattering matrix of the Transmission Line Matrix method (TLM)[13] can be obtained from the LBM method. The name Parflow is also used to emphasize that it is possible to use parallel processing with LBM [2], [12]. At the state of art, the Parflow has been used for prediction of CDMA signal propagation in urban micro-cells [2] and for propagation analysis in indoor environments [14]. We present the use of the Parflow method for prediction of UWB coverage in an hybrid indoor-outdoor area. The simulations are performed computing the pathloss in each point of the environment considering the material characteristics ($\varepsilon_r$ and $\mu_r$) of the existing obstacles in the area. The advantage of this method is to obtain a fast simulation by describing the environment and all the obstacles in 2 dimensions and considering only the central frequency of the transmitted UWB signal to estimate the attenuation. Normalization factors are used to consider the effect of the third dimension. A numerical example considering a typical pico-cell suburban area is presented. The transmitting antenna was placed outside the building and the analysis was done observing the pathloss inside and outside the building, including both the indoor and the outdoor environment. In order to validate the method the simulation results were compared with the measures done by [4] in the central frequency of 5.85 Ghz, which can be used for indoor UWB applications with 500 MHz of bandwidth, according to the FCC regulations [1]. The results show a good agreement of the standard deviation and the absolute value of the pathloss between the simulation and the measurements.

## INTRODUCTION

The UWB systems deployment must consider the radiating power limits given by the regulations [1] and take into account the absorption, reflection and scattering of the electromagnetic waves caused by obstacles in the environment. Depending on the transmitted power and the antenna position, the waves can cross the walls and arrive in one desired point with sufficient power level to be detected in an indoor environment.

The models used to analyze the system coverage area for a given antenna placement can be classified as *Deterministic* and *Stochastic* models [7]. The Parflow method is proposed as a deterministic approach to simulate the pathloss during the UWB propagation in an hybrid indoor-outdoor area, considering the material characteristics ($\varepsilon_r$ and $\mu_r$) of the existing obstacles. It is based on Lattice-Boltzmann methods (LBM), a class of computational methods based on lattice gas method or cellular automata using a Bhatnagar-Gross-Krook (BKG) [6] collision model. The scattering matrix of the LBM, with the correct choice of flux parameters is equal to the scattering matrix of the Transmission Line Matrix method (TLM) [14], [13], therefore this method is also used for propagation of electromagnetic waves [3]. There are examples in the literature of the use of LBM for prediction of GSM and CDMA signal propagation in urban microcells [3] and for propagation analysis in indoor environments [14].

The Parflow method will be presented and the main characteristics and theoretical background will be introduced. The simulation environment will be described using a two dimension grid of points and the Parflow will be chosen in order to allow the comparison between the simulation results and the measurements done by [4]. The conclusions and outlook for the applications of the algorithm for the evaluation of UWB propagation problems will be presented at the end.

## THE PARFLOW ALGORITHM

The PARFLOW algorithm describes a system going from the excited state to the equilibrium state, using a regular structure of data to allow parallel computation of the diffusion process. The Parflow can be classified as a time domain simulation method for electromagnetic propagation. The time average of the amplitude of the electric field is computed in each

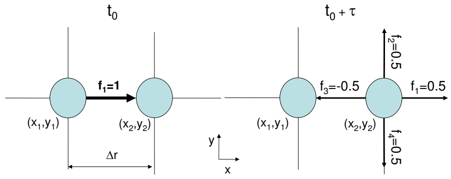



Figure 1: Evolution and Scattering in the Parflow Algorithm.

point [3], [2] and it is based on the direct discretization of the Huygens principle. Space and time are discretized in terms of finite, elementary units $\Delta r$ and $\Delta t$, and are related with the speed of light ($c_0$) and the space dimension $N_d$ by: $\Delta t = \Delta r \cdot (c_0\sqrt{N_d})^{-1}$. The free space wave equation for the scalar electromagnetic field component $u$ can be expressed by $\partial_t^2 u = c_0^2 \cdot \nabla^2 u$.

Let us consider each node connected to four neighbor nodes in a lattice. In this case, the scalar component of the electromagnetic field in the node is split up in five components, four that flows to the neighbors and rest value which remains in the node. We can define this flows $f_{i=1\ to\ 4}$ as the scalar quantity related to the fraction of the field component transmitted from one node to another following the lattice directions. The $f_0$ is defined as a rest flow that can be used to model dispersive effects of different materials [12]. The scalar field value in each node can be calculated at each time step summing the flows which come in or out from the node ($f_{in}$ and $f_{out}$ as follows [2]:

$$u = \sum_{i=0,4} (f_{in})_i = \sum_{i=0,4} (f_{out})_i \tag{1}$$

In our work we are only considering $i$ from 1 to 4. The exchange of the $f$ in the lattice is performed in two phases: the collision and the free displacement. The dynamic of the process is shown in the Fig. 1 with an example. If $f_1 = 1$ reaches one node at $t_0$ as indicated in Fig. 1, the the energy is scattered isotropically in all four directions. Therefore, at the time step $T = t_0 + \tau$ each neighbor node receives one fourth of the incident energy. The corresponding field quantity must be $1/2$ of the incident field in magnitude. The reflection coefficient in Fig. 1 must satisfy the requirement of field continuity at the node. If we repeat the same procedure for all directions we will end up with the scattering matrix W, as follows [3] [14] and:

$$\begin{pmatrix} f_1(x+\Delta r) \\ f_2(x-\Delta r) \\ f_3(y+\Delta r) \\ f_4(y-\Delta r) \end{pmatrix} = W_{\text{parflow}} \cdot \begin{pmatrix} f_1 \\ f_2 \\ f_3 \\ f_4 \end{pmatrix} = c_1 \cdot \begin{pmatrix} c_2 & c_2 & c_2-1 & c_2 \\ c_2 & c_2 & c_2 & c_2-1 \\ c_2-1 & c_2 & c_2 & c_2 \\ c_2 & c_2-1 & c_2 & c_2 \end{pmatrix} \cdot \begin{pmatrix} f_1 \\ f_2 \\ f_3 \\ f_4 \end{pmatrix} \tag{2}$$

When the parameters are $(c_1, c_2) = (1.0, 0.5)$, the scattering and the free displacement procedure in Parflow are numerically similar to the scattering and connection process in TLM with two-dimensional shunt node [12]. The General Parflow scattering matrix was presented by [12] and [2]. The parameters $c_1$ and $c_2$, in the range [0,1], are used to model different materials: perfect absorbers ($c_1 = 0$ and $c_2 = 0.5$), perfect reflectors ($c_1 = 1$ and $c_2 = 0$) and general medium ($c_1$ and $c_2$ in the range [0,1]). The Transmitter node represents a sinusoidal source in the position $r_0$. In this node all the outgoing flows are in phase, and the amplitude in each time step is given by:

$$f_i = \gamma \cdot \sin(2\pi t \cdot T^{-1}) = \gamma \cdot \sin(2\pi n \cdot \Delta t \cdot T^{-1}) = \gamma \cdot \sin(2\pi n \tilde{T}^{-1}). \tag{3}$$

The number $n$ indicates the successive iterations in the application of the method, the $\tilde{T} = T/\Delta t$ is the dimensionless period of the source and the factor $\gamma$ is a normalization factor defined by [12] that depends on T(the period of simulation) to obtain $u_{max} = 1$. The simulation is done in one frequency only for the UWB signal, which is possible due to the Fourier transform relationship between the channel impulse response in time domain and the channel transfer function in the frequency domain. It has been proved that this technique is an accurate time domain technique when real-time and near-field measurements are not required (See [7]). The simulation wavelength can be obtained using the procedure described by [12]. In a two dimensional squared mesh, the velocity of propagation is $c_0 \cdot \sqrt{N_d}$, where $N_d$ is the space dimension, the wavelength of the source is $L = \tilde{T}\Delta r$. The frequency of simulation depends on the mesh dimension $\Delta r$, the dimensionless period of the source $\tilde{T}$ and $N_d$. These parameters are related by the relation [12] and [9]: $f_{simulation} = c_o\sqrt{N_d}(\tilde{T}\Delta r)^{-1}$. The system coverage can be analyzed observing the pathloss by computing the amplitude of the steady state signals at the point $r$, as follows:

$$A(r,t) = \sqrt{\int_{t-2T}^{t} (u(r,k))^2 \cdot T^{-1}\, \mathrm{d}k} \tag{4}$$

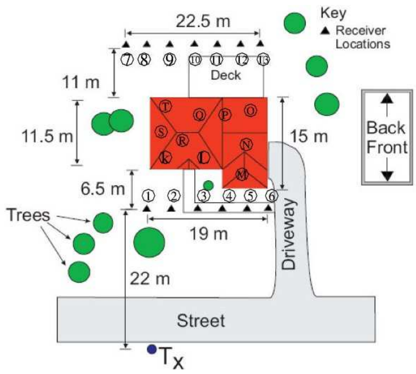
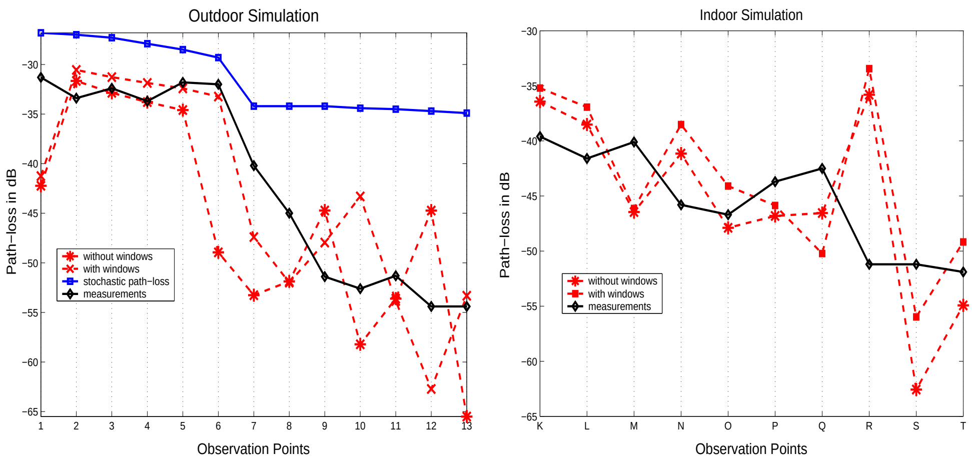



Figure 2: General View of the simulation environment.




(a) Simulation outdoor environment (b) Simulation indoor environment.

Figure 3: Simulation results compared to the measurements and to the stochastic model.

The results must be renormalized, because Parflow is a two dimensional method, therefore the 2 dimension results must be mapped in a three dimensional space [12]using the approximation $A_{3D}^{real}(r) \approx A_{2D}^{sim} L_0 \cdot (\pi L d'(r))^{-1}$. This renormalization varies as a function of the distance between the transmitter and the receiver (i.e. the Manhattan distance $(d'(r))$ as shown in [12]). The $A_{3D}^{real}$ is the amplitude of the real signal measured in the 3D environment, the $A_{2D}^{sim}$ is the amplitude simulated in the 2D environment, the $L_0$ is the wave length used in the measurements.The $L$ is the wave length used in the simulation that can be different in more general cases.

## SIMULATION RESULTS

The simulation was done in the environment described by [4], that is basically a typical suburban house surrounded by trees and with two floors. The house layout is shown in the Fig. 2. The thickness of the walls and the construction materials were estimated from the figures and the data presented in [4]. The typical absorption characteristics of the materials were taken from [8]. The environment shown in Fig. 2 has the following parameters: height of the transmitter 5 m, height of the receiver station 1.5m, height of the roofs of the buildings 5m. The receiving points were selected according to Fig. 2 and are in the position of the measurement points used in [4]. The receiving points 1-6 are in front of the house and are Line of sight (LOS), the points 7-13 are in the back of the house and are Non Line of Sight (NLOS), the Points O-M are inside(indoor) of the house and are (NLOS). The simulation area has 2000 X 2000 nodes with $\Delta r = 0.002$ m $< \lambda/10$, as recommended by [10] to obtain a good accuracy in the simulations. The electrical properties of the materials were used to calculate the (c1,c2), following the procedure introduced by [10]. The Table 1 also shows the attenuation values used to calibrate the values of (c1,c2), taken from the measurements done by [4]. The following parameters were used in this simulation: normalized source period $\tilde{T} = 10$, number of simulation time steps: 1000, source amplitude= 0.07 Volts, correction factor $\gamma = 0.304$, $N_d = 2$, $\tilde{T} \cdot \Delta_r = 2$ cm and $f_{simulation} = 5.850$ GHz. All the building had been considered with the height much bigger than the transmitter,according to [10].The boundaries of the simulation domain were implemented as introduced by [2], using three different layers of absorbers with following parameters: first layer (c1,c2)= (0.8,0.5), second layer (c1,c2)= (0.436,0.5) and the outmost layer (c1,c2)= (0.0,0.5).

The results are shown in Fig. 3(a) and Fig. 3(b). The results obtained with the stochastic path-loss model [5] and [4] are indicated in the Fig. 3(a). The mean error and the standard deviation of the values presented in Fig. 3(a) are -2.13 dB and 7.73 dB respectively for the simulation without the windows, and for the simulation including the windows they are -0.06727 dB and 6.5264 dB. From the Fig. 3(b), we can realize that the Parflow method presents results better than the stochastic approach [4], when compared to the measured values. The values in the indoor points are in general 10 dB lower than those from the outdoor points, which shows also a good agreement with the measurements. The biggest deviation from the measurements is in the point 1 (behind the tree, Fig. 3(a)) and it occurs because of the strong variation in the electric parameters of the wood and the foliage, which is difficult to include in the simulation. The strong deviation in the points 10 and **R** (behind and inside the house respectively, Fig. 3(a) and Fig. 3(b)), occurs because the internal objects of the house were not considered in the simulation and the attenuation computed in this point was caused basically by two external walls.

Table 1: The $c_1$ and $c_2$ for the obstacles.

| Obstacle | $c_1$ | $c_2$ | Attenuation |
|---|---|---|---|
| exterior wall | 0 | 0.76 | 12.6 dB |
| internal wall | 0 | 0.15 | 4.1 dB |
| windows | 0 | 0.68 | – |
| trees | 0 | 0.15 | 8.4 dB |

## CONCLUSION AND OUTLOOK

The presented approach is an excellent solution for simulations involving complex environments with different kind of obstacles composed of different materials. The absorption characteristics of each obstacle in the simulation environment can be included in a fast and systematic way using a two dimension description, what leads to increase the accuracy of the propagation analysis and to improve the system coverage. The power of the proposed approach has been analyzed and demonstrated with an example and the compared with real measured values done by [4] in a hybrid outdoor and indoor environment. It is possible to increase the results accuracy through the better description of the obstacles and using better discretization of the simulation domain. The Grid technologies [11] can be used together with this method to increase the performance in the simulation time for bigger areas.

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