Modified Version of de Jong Radiopropagation Model

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***Abstract* — a semi deterministic propagation model based on De Jong recommendations is described. It is an extended 2D-ray tracing model for planning microcell in urban environment. It uses virtual sources, in order to model the Wave Propagation phenomena (building transmissions, tree scattering, diffraction by external corners, and wall reflections) of a base station emission that may reach even hidden buildings out of the line of sight even far beyond visible buildings, but also takes into account the channel influence in signal parameters like complex amplitude and frequency. New concepts and modifications introduced by the authors to achieve a practical implementation are also described. The article pretends be ready to implement description of the model and provide details of the way to identify and characterize Virtual Reflection Sources, and Virtual Diffraction Sources. Virtual Scattering Sources have not been completely specified yet. The model would play a key role in planning UHF networks that is the case of future implementation of IMT- Advanced.**

Keywords: radio propagation, mobile communication, ray-tracing, wireless channel, urban microcells.

I. INTRODUCTION

The use of microcells and UHF spectrum in Modern Wireless Communications is constantly rising, due to more and more demand on data bandwidth. The exponential demand on UMTS, WiFi, ZigBee, UWB or future 4G communication system services is an example of that.

Mobile communication systems usually used antennas located in top and at frequencies enough to radiate over houses roofs and around buildings to cover few kilometers around a base station (BS). Radio propagation models like Hata or Walfish-Ikegami were popular for doing simulations for planning radio coverage in these cases. But they do not work out more in urban environment when using antennas located bellow building roofs and wavelengths less than few meters, which is actually the tendency. Wall Reflection, Corner diffraction, tree dispersion and wall crossing are the main mechanisms to provide coverage in these conditions. The use of Uniform Theory of Diffraction (UTD), in this case, results to be more relevant and leads to improve ray tracing radio propagation models. First ray tracing models are well known as brute force type, because a great quantity of radiated rays from a Base Station (BS) is taken into account along complicated propagation paths. The main disadvantage of these models is computation complexity.

New strategies to improve ray tracing models have been inspired on Huygens Principle. Thus, new models usually consider wave reflections, diffractions and dispersions as a set of Virtual Sources (VS) with specific radiation beam form called Illumination Zone (IZ) that derives from interaction of BS with buildings and their walls. An example of a VS and its IZ is shown in the section IV. In this way, the problem can be reduced to find out all VS. As they radiate in Line of Sight (LOS), calculations may dramatically drop down. 2-D phenomenon is usually considered. There are many tools implementing 2-D ray tracing model. Most of them calculate LOS path loss, and energy contribution from wall reflections and external corner diffractions. In 1997 Yvo Léon Christiaan de Jong began doing radio propagation experiments in different urban environments to identify the causes of the considerable deviation usually found between measured and simulated radio coverage with the help of well known ray tracing models. He demonstrated that it is relevant to place VS beyond visible buildings, which means, in other words, that transmission of waves through buildings is relevant. He also demonstrated the relevance of taking into account diffractions by internal building corners, tree coherent and incoherent scattering near street corners.

De Jong's work is mainly focused on demonstrations, deductions and recommendations for planning urban microcell coverage [1], [2], [3], [4], [5], [6], taking into account the most relevant UTD effects to reach near to reality predictions with moderate calculation complexity. His work, condensed at his doctoral thesis is what we here call De Jong Radio propagation Model [7]. Currently RadioGis Research Group[1] is in charge of the implementation of an algorithm for De Jong Model as part of a set of projects, where also takes part I2T Research Group[2] to produce a tool to support radio spectrum management. For this purpose, it was necessary to formulate a model according to De Jong recommendations. It was also necessary to introduce some new concepts, like Virtual Transmission Channels, De Jong Pixel, and other facilities, which result in The Modified De Jong Radio Propagation Model described here.

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[1] Research and Development Gruop at UIS University: http://radiogis.uis.edu.co

[2] Research and Development Group at Icesi University: http://www.icesi.edu.co/i2t/

II. Assumptions And Limitations Of De Jong Model

- The model is adequate when transmission and receiving antennas heights are located well below the average rooftop level, which is normally the case in urban microcells. Ground reflections and rays over rooftops are neglected.
- Perpendicular polarization of the electric field is assumed.
- It has been assumed that such parameters like geometrical and dielectric features of the environment, location of the base station antenna, location of the observation points, the frequency, etc. are deterministic, constant and exactly known. The predicted channel parameters have therefore also deterministic and constant nature.

III. Virtual Channels Under Building Transmision

A BS with a complex set of reflection, diffraction and dispersion effects is transformed to a set of elementary virtual sources (VS) without these effects. Here, we introduce the term - Virtual Channel (VC), in order to calculate energy contribution from a VS to a Point of Interest (PoI). This kind of sources radiates waves that may propagate only forward through air and buildings suffering only path loss and signal parameters (amplitude, phase and frequency) alterations, Fig. 1. It can be understood that the real channel between a BS and PoI would be a composite of VCs.

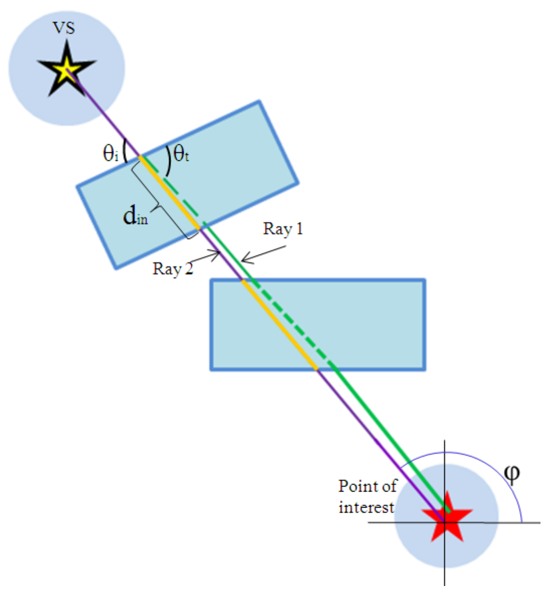

Figure 1. A Virtual Reflection Source from a BS.

A VC is associated to VS, its radiated signal and radiation pattern, the PoI, and the obstacles between the VS and the PoI. The primary purpose of the VC is to get signal parameters at the PoI.

First of all, it is necessary to determine if the VS is a valid source for the PoI. It happens when the IZ of the VS covers the PoI. In this case, distance between VC and PoI has to be calculated to be used as entrance to path loss equation:

$$L_{fs}(dB) = 10 * \log_{10}\left(\frac{4\pi d}{\lambda}\right)^n \quad (1)$$

Where d is the path distance in meters, λ the wavelength in meters and n - the propagation decay law. Our implementation used n=2 or n=4 depending on the antenna's height, as recommended in [8] for near earth propagation.

Propagation through buildings is accompanied with additional path loss. The transmission coefficient T(**r**) indicates the transmitted signal portion. Effective attenuation constant α_b in (dB/m) characterizes the signal amplitude attenuation when the ray is crossing a building with unknown interior. As shown in Fig. 1, when a ray crosses a building it experiences a few deflections (ray 1). But its incidence angle θ_i is nearly the same as its transmitted angle θ_t, so it can be assumed the ray is straight (ray 2). The building transmission path loss for each building is calculated as:

$$L_t(dB) = \alpha_b d_{in} - 20 * \log_{10} T(\boldsymbol{r}) \quad (2)$$

Where d_{in} is the transverse distance within the building.

The phase variation is calculated as:

$$\phi = k_1 * d \quad (3)$$

Where k_1 is the wave number, which depends on the wavelength and the constant α_b as shown in equation 4.

$$k_1 = \frac{2\pi}{\lambda} - j\frac{\alpha_b}{8.686} \quad (4)$$

However usually $Im\{k_1\} << Re\{k_1\}$, and taking into account this, the imaginary part from (4) can be neglected [5].
De Jong proposes to use the Fresnel equations to compute T(**r**):

$$T(\boldsymbol{r}) = 1 - R(\boldsymbol{r})^2 \quad (5)$$

$$R(\boldsymbol{r}) = \frac{\cos\theta_i - \sqrt{\epsilon_r - (\sin\theta_i)^2}}{\cos\theta_i + \sqrt{\epsilon_r - (\sin\theta_i)^2}} \quad (6)$$

where $\epsilon_r = \epsilon + j60\sigma$ is the complex permittivity, ϵ is the permittivity of the building, σ is the conductivity of the building, θ_i the incidence angle of the ray and $\boldsymbol{r}$ is the boundary point.

A program that computes the incidence angles between a ray and all the buildings decreases the computer performance. As an alternative solution we propose to regard the transmission coefficient T(**r**) like a constant obtained from measurements, as this result is acceptable [9].

If representing the power of the virtual source as P_{source}, then the power at the PoI may be calculated as:

$$P_{point}(dB) = P_{source}(dB) - L_{fs} - L_{total}(dB) \qquad (7)$$

Where L_{total} is the sum of path loss due to all buildings between the VS and de PoI. Path loss, for each building, can be calculated by (2).

The Angle of Arrival (AoA) φ has to be also identified by the VC, to be used in final estimation as will be explained later. Simple geometry may be used for that.

Finally, the receive field is weighted by the envelope of the antenna's radiation pattern in the direction of the launched ray.

IV. RAY TRACING

De Jong bases his 2D Ray Tracing proposition on previous works [9], [10] where the concept of virtual sources that result from reflection have been brought in for first time. De Jong contribution consists in the demonstration of the relevance of interactions of a ray not only with building walls in front of a source, but also with walls behind the front buildings.

A. *Identificacion of virtual refexion sources (VRS).*

Let us suppose that we have a Region of Interest (RoI) where two buildings and a Base Station (BS) with omnidirectional diagram are placed, as shown in Figure 2. For pedagogic purpose we will use the term Mirror to indicate a wall that plays a similar role like a mirror to incident light. In Figure 3, the mirror M1 radiates energy the same way as if a virtual source VRS(1) would exist independently from the BS. In this case, the BS plays the role of Parent Source (PS) and the VRS(1) the role of its child. A PoI located inside the Illumination zone IZ(1) of this source would receive power from both the parent and de son. A VRS correspond to the parent source when rotated around the rotation axis that lies on the mirror, as shown in Figure 2. Rotation axis is an extension of the mirror to the side that is closer to parent. The IZ is the light beam formed by the mirror as shown in Figure 2.

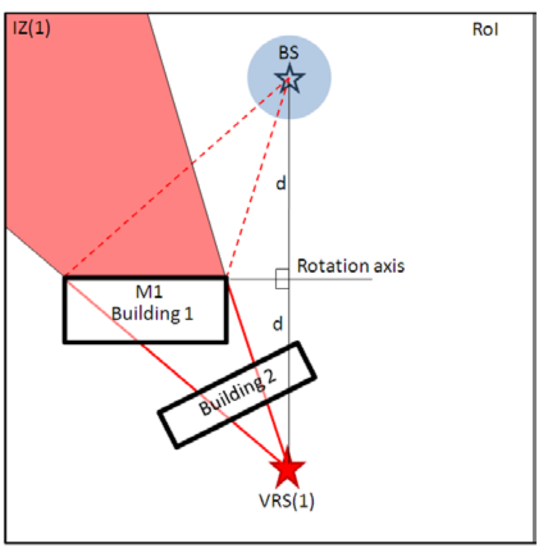

Figure 2. A Virtual Reflection Source from a BS.

Figure 3 shows a study case where five different mirrors take place: M1 to M5.

They correspond to the walls located in front of the parent source. Before De Jong, only mirrors M1 to M4 would have been taken into account. M5 corresponds to a special case proposed by De Jong who was the first one that took interest in building transmission. This piece of wall receives different energy than piece M4. In fact, the signal received at M5 first passes not only a free space path from parent source but also crosses a building. That is why two VRS appear at the same location, but they are different in their IZ and power.

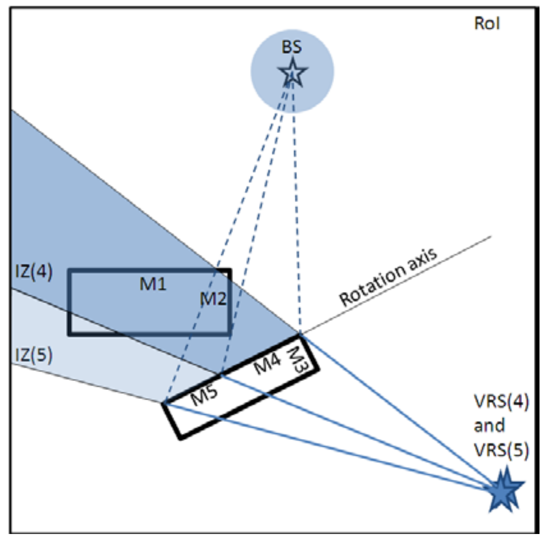

Figure 3. Two Virtual Reflection Sources when building transmision takes place

Finally, if mirrors M2 and M3 are taken into account, then we get the whole group of VRSs for the RoI as shown in figure 4.

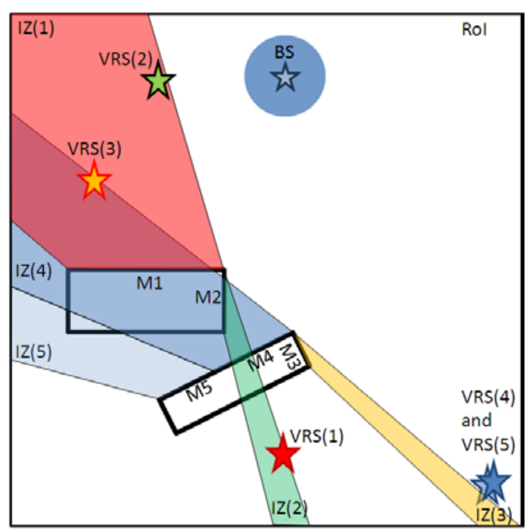

Figure 4. Resulting Virtual Reflection Sources from a BS

B. Our adaptations and modifications

- Some characteristic of the VRS, such as IZ and location have been already described. The idea is that a VRS radiates a signal that corresponds with the signal radiated by the parent source, but its seems to be affected by buildings crossing, and mirror-wall properties, as described in chapter III. Only free space path loss has not to be taken into account due to that a VRS is located at the same distance, as its parent source, to its mirror-wall. This can be seen in figure 4, where distance to rotation axis is the same for the parent and the VSR.

- De Jong allows VRS to appear when transmissions through take place, but, how many buildings may be crossed? De Jong's answer to this question is from the point of view of two main experiments he did. In one case 2 buildings were crossed, but in other case were 4. But surely, if he had used more power on the BS, the number of crossed buildings would have been higher. The modification we propose lets automatically detect the building transmission order by using a decision threshold for the VC output signal. This means that a new VRS would be created only if the power of this signal is enough to be taken into account.

- For practical implementation it is not convenient to get second-order virtual sources, until all first order diffraction and Scattering sources have been found. In other words, until chapter VII we should not speak about higher order sources.

V. Diffraction Virtual Sources

When an obstacle like a knife-edge is illuminated in one side, the other side is not completely shaded. It is due to Huygens' Principle which establishes that every point in a wavefront acts like a source of new waves, in this case in the corner. As mentioned by De Jong, building corner may be seen like a finite conducting wedge and therefore as a wave source. But he does not describe a specific diffraction model for this case, but, for practical purposes, he recommends to implement one of those recommended by ITU-R based in the UTD (Uniform Theory of Diffraction) [11]. For a full practical implementation of the algorithm we propose to change each corner by a source which is not omnidirectional, its radiation pattern depends on the calculation of the signal power in the point of interest as following:

$$E_{UTD} = E_0 \frac{e^{-jks_1}}{s_1} D_{\parallel}^{\perp} * \sqrt{\frac{s_1}{s_2(s_1+s_2)}} * e^{-jks_2} \qquad (8)$$

Where E_0 represents the signal amplitude at the BS or VRS located at a distance of s_1 from the corner; s_2 indicates the distance between the corner and the point of interest, k is the wave number and $D_{\parallel}^{\perp}$ represents the diffraction coefficients for parallel and perpendicular polarization components and depends on the building corner geometry and the coordinates of the corner, point of interest and the generator, see [11]. In this case, perpendicular polarization is used because it is more useful for outdoor transmissions analysis.

These new virtual sources are similar to all other virtual sources used in the model, and like them, radiate a signal with amplitude that is calculated from the information of the parent source signal and the point of interest, in this case the position of the corner. The proposed algorithm introduces (8) in the VC that attend the signal from the virtual diffraction source (VDS), so the interaction between them takes into account the radiation pattern by default. The properties of the VDS are very similar to the properties of the VRS, for that reason, the VDS can also be considered by the same VC.

VI. Scattering Virtual Sources

The effects of de trees in the wireless communication channel for microcells must not be neglected because our urban environments have many of them, then the scattered field by trees is very important and common. Our proposal is to consider that the trees are new sources, that we called virtual scattering sources (VSS), like the VDS and VRS the VSS are virtual sources and can be also analyzed by de VC.

The properties of the VSS are very different from the others VS; first, this kind of VS is omnidirectional, because the incoherent field produced illuminates in all directions, second, for compute the attenuation the equations used (see [12]) are not similar to diffraction or reflection equations. However, the VSS has the basic source properties, wavelength, amplitude, phase et cetera, and for this reason is other new source.

Another difference is its illumination zone (IZ) because in this case the IZ is circular as shown in figure 5.

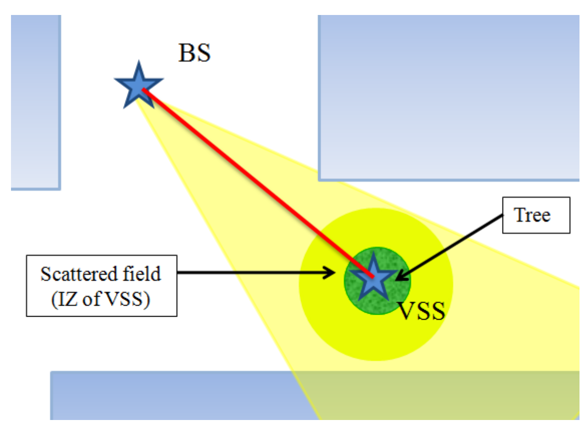

Figure 5. Resulting Virtual Scattering Sources from a BS and its illumination zone.

To describe the behavior of the radiation from the VSS we describe the trees like finite cylinders, but it is only a model because for the software implementation the tree has only one coordinate and this point is the place of the VSS.

VII. HIGHER ORDER DESCENDENCE

Typically only first order sources were used before De Jong, who did many practical experiments and simulations to demonstrate the importance of using second and higher order virtual sources. This means that every first order virtual source has to play the role of the BS to produce second order sources, and so on for higher orders. He found different figures for the highest order when using reflection sources, scattering, building transmission, or diffraction. For example, for an experiment done at Bern city [7] De Jong realized that it is enough to use building transmission order 3, reflection order 4, and scattering order 0, to obtain adequate power prediction. Nevertheless, other experiment done at Fribourg city [7] shows that transmission building order 1, reflection order 2 and scattering order 1 is the most adequate. This means that there are no valid values for every RoI. The problem is how to determine the highest order for every case? The solution we propose lies in a method to characterize the power of a virtual source with the help of the VC. We only had to include that the power of a new virtual source has to be compared with a predefined threshold to decide whether the source exists or not. It is convenient to use that threshold inside the VC, so that the logic of the VC could decide if the output signal is enough or not for a child virtual source to appear. This way, the amount of unnecessary sources dramatically drops down.

Another important problem detected during the implementation done at RadioGis is the convenience of automatically structuring the source tree depending on propagation and diffraction conditions of the RoI, rather than being predefined. To solve this problem we propose to consider that all sources, regardless of what type they are (reflection, diffraction or scattering), may suffer second or higher order reflection. The following steps are part of the proposition:

Step 1: find out all first order virtual reflection, diffraction and scattering sources (VRS, VDS, VSS) formed directly by the BS in the way described in passed chapters.

Step 2: Take each one of the virtual source regardless of its type instead of the BS and repeat step 1 for each of them. This way second order sources are obtained as shown in diagram of the figure 6.

Step 3: Repeat step 2 recurrently for every newly source until the corresponding VC indicates that the out power in not enough to generate a child source.

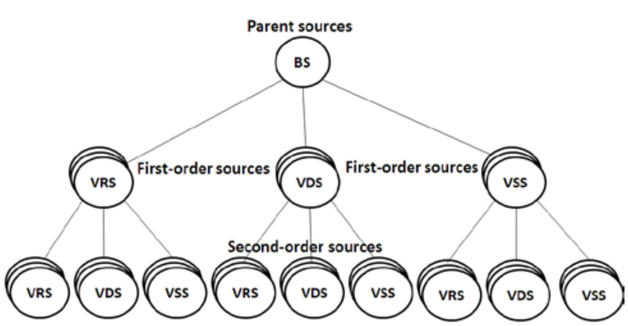

Figure 6. Example of a Source Tree.

VIII. PIXEL DE JONG

De Jong proposed an original method to calculate the signal power for an elementary observation area, that we call Pixel De Jong Local Mean Power (LMP) in the pixel has to be calculated. De Jong used square and circle areas. The dimensions depend on the desired spatial resolution of the prediction, but they are typically in the order of several tens of wavelengths. An example from [7] uses square pixels of 5m x 5m.

Amplitude, phase, length and AOAs of each traced rays are used to estimate various channel parameters

Estimation of LMP is based on spatial average (SA) of received power over a given observation area or pixel, it does not require ray-tracing for more than one observation point per pixel and which is more generally and accurate than the commonly used method so-called sum-of-individual-ray-powers (SP) to remove small-scale fading effects from prediction results. Next steps are proposed:

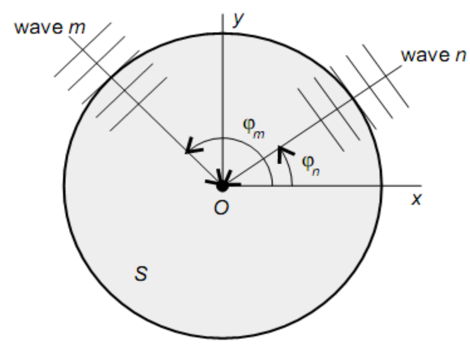

Figure 7. De Jong Pixel. φ_n and φ_m are AoA of waves n and m at the pixel S. Figure taken from [7]

- Choice of the pixels of interest from a user predefined trajectory or area. An Observation Point (OP) have to corresponds to the center of a pixel
- Calculation of the complex electric field amplitudes contributed by each valid sources to the OP
- Calculation of mean power to each pixel.

- Calculation of the Angle of arrival, (AoA), of incident wave over a pixel. It is the angle between the horizontal line and the direction of the wave

De Jong begins with a proposition for complex ray amplitudes:

$$s(x,y) = \sum_{n=1}^{N} \mathrm{u_n}\, \mathrm{e}^{\mathrm{j}(\mathrm{k}(\mathrm{x}\cos\varphi_\mathrm{n} + \mathrm{y}\sin\varphi_\mathrm{n}) + \phi_\mathrm{n})} \quad (9)$$

So that received power is:

$$p(x,y) = |s(x,y)|^2 \quad (10)$$

De Jong proposition for the LMP calculation (his method is a spatial average (SA)) is:

$$\bar{P} = \sum_{n=1}^{N} u_n^2 + 2\sum_{m=1}^{N}\sum_{n<m} u_m u_n Re\{\rho_{mn}\} \quad (11)$$

Correlation between m-th and n-th multipath signal in the surface S.

$$\rho_{mn} = \iint_S e^{j(k(x\cos\varphi_n + y\sin\varphi_n)+\phi_n)} \times e^{-j(k(x\cos\varphi_n + y\sin\varphi_n)+\phi_n)} f_X(x,y)\, dx\, dy \quad (12)$$

If all multipath signals are almost completely correlated ($|\rho_{mn}| \cong 1, m \neq n$), then $Re\{\rho_{mn}\} \cong \cos(\phi_m - \phi_n)$, and the LMP is well approximated by the received power at the OP 0, which is calculated as the power of the vector sum of the individual signals:

$$\bar{P} = \left|\sum_{n=1}^{N} u_n e^{j\phi_n}\right|^2 \quad (13)$$

For rectangular observation area centered at 0, with sides of lengths D_x and D_y aligned with the x and y axes, respectively, ρ_{mn} can be written as

$$\rho_{mn} = \frac{\sin\left[\frac{kD_x(\cos\varphi_m - \cos\varphi_n)}{2}\right]}{\frac{kD_x(\cos\varphi_m - \cos\varphi_n)}{2}} \times \frac{\sin[kD_y(\sin\varphi_m - \sin\varphi_n)/2]}{kD_y(\sin\varphi_m - \sin\varphi_n)/2} e^{j(\phi_m - \phi_n)} \quad (14)$$

The predicted local mean power along a measurement trajectory can be obtained by locally orienting the (x,*y*) coordinate system with the *x* axis parallel to the trajectory, making D*x* equal to the averaging interval applied in the measurements, and letting $D_y \rightarrow 0$, so that the second factor vanishes. For circular observation area of diameter D centered at 0, ρ_{mn} becomes

$$\rho_{mn} = \frac{2J_1(kDsin[(\varphi_m - \varphi_n)/2])}{kDsin[(\varphi_m - \varphi_n)/2]} e^{j(\phi_m - \phi_n)} \quad (15)$$

Where $J_1(\cdot)$ is the Bessel function of the first kind of order one.

Finally, for the prediction of the mean power received along a horizontal circle centered at 0 with diameter D (ring-shaped observation domain), ρ_{mn} is given by

$$\rho_{mn} = J_0(kDsin[(\varphi_m - \varphi_n)/2]) e^{j(\phi_m - \phi_n)} \quad (16)$$

Where $J_0(\cdot)$ is the Bessel function of the first kind of order zero.

IX. Some Experimental Results

After the software implementation of this algorithm it was necessary to make a tuning of its parameters based on some measurements. A final measurement campaign was made in Bucaramanga; the simulation was done using dry brick's electric properties to model the buildings and making calculations for the others parameters [16].

Figs. 8 and 9 show the behavior of the algorithm's simulation and the measurements of the campaign at specific chosen points. It is easy to see that the correlation between the two graphics is very good having in account that the equipment used to make the measures cannot take measures under -80 [dBm].

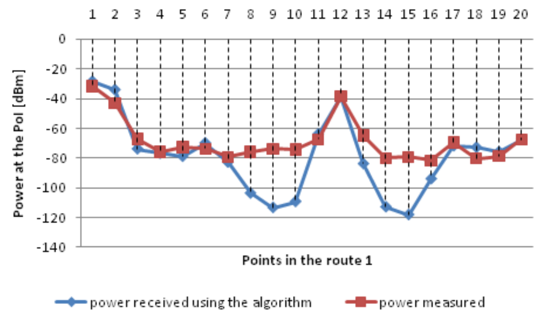

Figure 8. Route 1 of the measurement campaign.

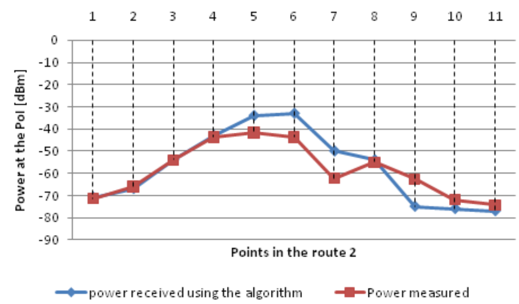

Figure 9. Route 2 of the measurement campaign.

The results of the simulation were computed in a few seconds in a regular computer using free software.

Tables I and II include just the values over -80 [dBm] used in the figures 8 and 9 respectively.

TABLE I
NUMERICAL VALUES OF THE ROUTE 1

Point	Power measured	Power computed
1	-31,7	-28,51
2	-43,1	-34,14
3	-67,2	-73,94
4	-75,7	-76,92
5	-72,7	-78,94
6	-73,6	-69,96
11	-67,4	-63,94
12	-38,6	-38,67
17	-69,53	-71,94
18	-80,3	-72,94
19	-78,8	-75,94
20	-67,5	-67,62

TABLE II
NUMERICAL VALUES OF THE ROUTE 2

Point	Power measured	Power computed
1	-71,3	-70,94
2	-65,9	-66,94
3	-53,9	-53,94
4	-43,6	-42,94
5	-41,7	-33,94
6	-43,7	-32,94
7	-62,2	-49,94
8	-54,9	-53,94
9	-62,6	-74,94
10	-71,9	-75,94
11	-74,2	-76,94

Making the calculations with the values of the tables I and II, the mean error between the experimental and the measured results, e_m, can be obtained. For the route 1 e_m=4,667 [dB] and for the route 2 e_m=6,775 [dB].

X. Conclusions and Further Work

We have proposed a modification of DeJong model, with some improvements in computational complexity and range of application, to demonstrate the computational efficiency another algorithm with the same purpose will be developed, however, in the form of programming we can already notice the advantages of this algorithm because is OOP-based .

We have implemented the model in a simulation tool written in Java and now we are testing the model with measurements results using a Cost 2100 Reference model and others.

The idea of a virtual channel (VC) that can analyze every type of sources (VRS, VDS and VSS) reduces the complexity of the algorithm, for understanding and implementing, and makes it much more accurate and fast.

Even designing very accurate algorithms is very difficult make good comparisons if the measurements equipments cannot get weak signal levels.

The virtual channel could be improved with the theory of the two-ray channel and the dual-slope model.

Acknowledgment

This work is part of a global project with finance support from Colombian state (represented by Colciencias and SENA), UIS University (Universidad Industrial de Santander, poject code 8538), Icesi University, with technical support of Colombian Ministry of Communication Information Technology (Ministerio de Tecnología de la Información y Comunicación), Tesamerica Enterprise and Inkco company.

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