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Accuracy Enhancement of a Multi-Resolution Indoor Propagation Simulation Tool by Radiation Pattern Synthesis

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Introduction

Regarding the strong development of wireless LAN systems melting various technologies in the same area, coverage prediction tools appeared necessary for fast and effective deployments. Numerous methods have been studied in this framework, almost based on asymptotic theories (e.g. ray-tracing) [1-5]. Actually, in a complex environment with multiple reflections and diffractions resulting in a large angular spread, a ray-tracing approach provides fast results only if few rays or reflexions are taken into account, resulting in a lack of accuracy. Ref. [6] proposes a new alternative to these techniques derived from classical TLM (Transmission Lines Matrix) methods [7] and calculating flows exchanged between cells corresponding to a spatial discretization of the environment. This innovative approach offers both a precise modeling of the propagation environment and a reduced computational load taking advantage of a multi-resolution algorithm. In this approach, radiating sources are simulated as point sources and are thus obviously omnidirectional leading to an important limit of the method. This paper tackles this problem by introducing multi-point sources. A regularized radiation pattern synthesis is then proposed for modeling particular radiation patterns. This approach enhances the accuracy of the predictions while preserving fast calculation times.

MR-FDPF method limits

The Multi-Resolution Frequency Domain ParFlow (MR-FDPF) algorithm has already demonstrated fast and accurate prediction results for indoor propagation [8, 9]. In the ParFlow model [10] a source is simulated as an elementary pixel delivering four equivalent flows. By the way a radiating source simulated with this method is naturally omnidirectional. However, in a deployment-oriented point of view, a more complete definition of the radiating sources is needed : any kind of access point (AP) should be modeled, taking into account the antenna directivity. We propose herein a method to form a desired radiation pattern based on the principles of beamforming techniques. In wireless systems omnidirectional antennas like dipole or whip are widely used, but directive antennas are also more and more often preferred, either to increase range or to efficiently customize the deployment. In 802.11 networks, 6 or 8 dBi gain antennas (e.g. patchs) are often integrated in access points. Representing the radiation of such non-uniform pattern with only four simple flows is intrinsically unfeasible. The use of several sources with appropriate weighting is then needed. Thus, the radiated function can be controlled by adjusting magnitude and phase of each source:

$$F(\theta) = \sum_{n=1}^{N} x_n e^{-j\beta d \cos\theta} \tag{1}$$

where x_n is the complex weight of each source, d the distance between two sources and θ the angle of the considered direction for a linear array of N elements. This approach is

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nothing else than a well-known array synthesis technique. To properly create a complex radiation pattern, a block of NxN elementary sources is used.

Radiation Pattern Synthesis

Radiation pattern synthesis is a well-known problem in the field of array antennas. A classical approach [11] considers the expression (1) as a discrete Fourier transform (DFT) and then extracts the source weights by an inverse DFT. This method is simple and efficient for basic beamsteering applications where only few criteria are needed (maximum gain and half-power beamwidth for example). Due to the spatial sampling, the resolution of this technique depends directly on the number of sources used. Unfortunately oversampling is actually not efficient, leading to undesired additional side-lobes in the radiation pattern.

Our aim is there to propose a method offering a good approximation of a given radiation pattern with a fixed number of uniformly spaced sources. In this way, our choice focused on a formulation with independence between the number of constraints and the number of weights searched. Calling $\vec{z}$ a vector representation of the desired radiation for each direction and $\vec{x}$ the weighting vector, we can build:

$$\vec{z} = H\vec{x} \tag{2}$$

with

$$H = \begin{bmatrix} 1 & \cdots & e^{j2\pi((N-1)\cos\theta_1 + (M-1)\sin\theta_1)} \\ \vdots & \ddots & \vdots \\ 1 & \cdots & e^{j2\pi((N-1)\cos\theta_n + (M-1)\sin\theta_n)} \end{bmatrix} \tag{3}$$

for a NxM array of sources with *n* fixed directions.

In these expressions, the number of fixed points in the radiation pattern appears adaptable, impacting the size of *H*. Then, computing the generalized inverse of *H* reveals the weights to impose to our NxM sources to correctly approximate the pattern according to:

$$\hat{x} = \frac{H^{\dagger}}{H^{\dagger} H} \vec{z} \tag{4}$$

To prevent important oscillations between fixed reference points, two regularization terms are introduced:

$$\hat{x} = \frac{1}{H^{\dagger} H + \mu_0 D^T D + \mu_1 I} H^{\dagger} \vec{z} \tag{5}$$

with

$$D = \begin{vmatrix} \ddots & \ddots & \ddots & \ddots & & \\ \ddots & \mathbf{-1} & \mathbf{1} & \mathbf{0} & \mathbf{0} & \\ \ddots & \mathbf{0} & \mathbf{-1} & \mathbf{1} & \mathbf{0} & \ddots \\ \ddots & \mathbf{0} & \mathbf{0} & \mathbf{-1} & \mathbf{1} & \ddots \\ & \mathbf{0} & \mathbf{0} & \mathbf{0} & \ddots & \ddots \end{vmatrix} \tag{6}$$

and *I* the identity matrix. The terms μ0 and μ1 are adjusted to control the smoothness of the radiation pattern.

The reference radiation pattern used to evaluate and adjust our solution is a simple sinus function with no backward radiation, assuming that it is a good approximation of classical patch-like antennas. To properly simulate AP the study focuses on the front-to-back ratio. This reference pattern produces a theoretical power map as represented in Fig. 1 (left) in free-space. An array of 3*3 elements spaced from $\lambda/6$ with weights estimated by (5) yields power predictions illustrated in Fig. 1 (right). It appears that the estimated radiation fits well with the theoretical one. Although some backward radiated lobes are observed, the resulting front-to-back ratio remains good with 34 dB which is greatly sufficient to accurately model directive access points. It should be noticed that increasing the number of sources can increase the accuracy. Based on these results this algorithm was implemented in our MR-FDPF based wave propagation simulator.

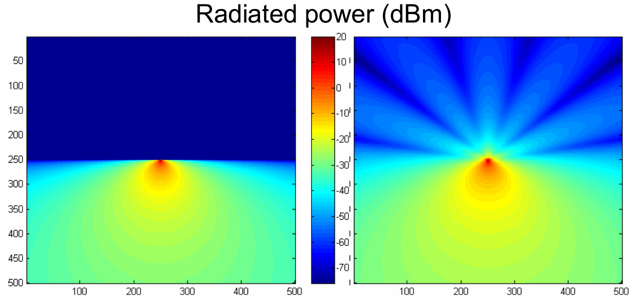

Figure 1. Radiated power in a 500x500 cells free space (5 cm step) for a 20 dBm EIRP
Left : desired, Right : 3x3 weighted sources ($\lambda/6$ spacing).

Figure 2 shows a comparison of two coverage predictions of the same environment (71 by 17 meters with a 5 cm resolution at 2.45 GHz). This illustrates the impact of the radiation pattern of a 120° beamwidth antenna used instead of an omnidirectional one (with the same EIRP). The directive antenna is simulated with a 6x6 array with $\lambda/6$ spacing. In both cases the pre-processing time of the environment is 5.6 s (on a P4 3.2 GHz with 2 Go memory). Taking advantage of the multi-resolution principle, a propagation time of only 0.8s is achieved for the 6x6 sources (instead of 0.2 s for the omnidirectional one). So the computational cost of this approach remains very low, even with 36 point sources.

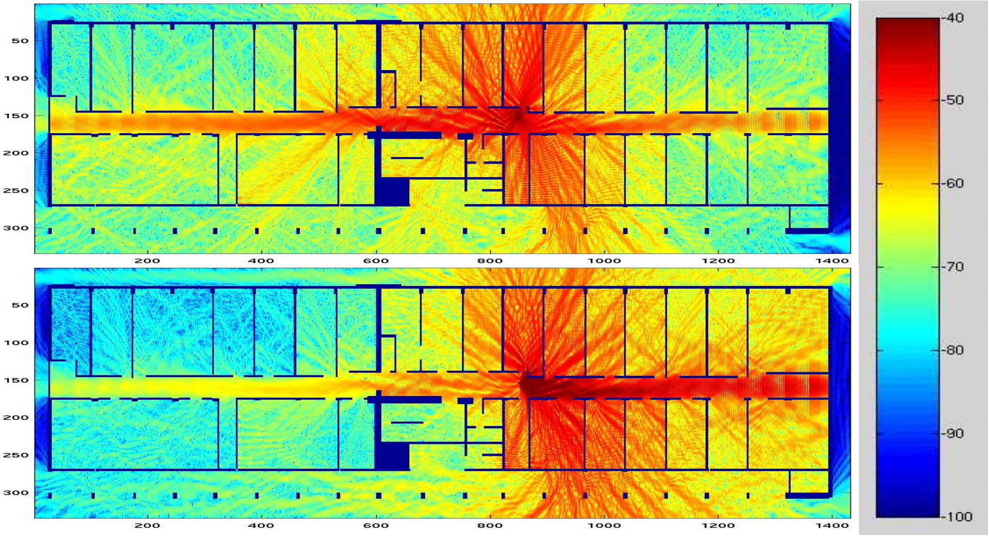

Figure 2. Coverage predictions (dBm) for an omnidirectional access point (upper) and a directive one (lower) pointed in the right direction with same 17 dBm EIRP.

Experimental results

Then to validate this method a comparison of the results obtained for 100 reference measurements in the same environment was performed with a 180° beamwidth AP. In terms of Root Mean Square Error (RMSE) between predicted and measured signal, the classical approach (omnidirectional source) leads to a precision of 5.8 dB. With the radiation pattern synthesis the RMSE falls to 4.4 dB, providing a 1.4 dB increase in the prediction quality. More tests have to be done and even better improvement could be expected with AP having a higher directivity.

Conclusion

The proposed approach to model a desired radiation pattern in a TLM based fast propagation engine appears relevant without notable increase of the computational cost. A promising forthcoming work now concerns the evaluation of smart antennas or MIMO systems in indoor environments. Our simulator is indeed a good candidate for such simulations due to the natural high spatial resolution.

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