DEVELOPMENT AND EVALUATIONS OF PHYSICAL AND COMPUTER OPTIMIZATIONS FOR THE 3D UTD MODEL

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ABSTRACT

This paper presents a solution to the problem of computing the wave propagation in a 3D environment. We first propose a new algorithm that allows to find all the paths containing diffractions and reflections in any order. Then we propose two optimizations easy to make. These three new proposals are tested, and some results are presented and discussed.

INTRODUCTION

Different authors have presented solutions for the prediction of radio coverage. For instance Cichon [1] proposed a solution which works in micro-cells for cellular system of wireless communication. Legendre [2] proposes a solution for a 3D ray-tracing implementation, by using the Uniform Theory of Diffraction [3]. This solution is based on the gradient method [4] in order to find the propagation paths containing diffraction points. It is restrictive, i.e. it limits paths to those of the type $R^*D^*R^*$, where R is a reflection point, D is a diffraction point, and the upper script star denotes zero or any number of successive points we want. Moreover, Legendre emphasizes the fact that these path search computations are much more expensive than those in 2D. This point is obvious, since such computations are done with one more degree of freedom, and since they are based on a numerical method, but on an analytical one in 2D.
These points show that the 3D computations, needed in urban cases, must be extended to all the possible paths and optimized in order to be usable. In this contribution, we propose such a work. In the first section, we explain our new algorithm that allows to compute a path containing reflection and diffraction points in any order. In the second, we propose two optimizations in order to reduce the time computation of a 3D-attenuation evaluation. Next, we show and discuss some results in urban situation.

1. GENERAL PATHS COMPUTATION

1.1. Analytical Solution for One Diffraction Paths

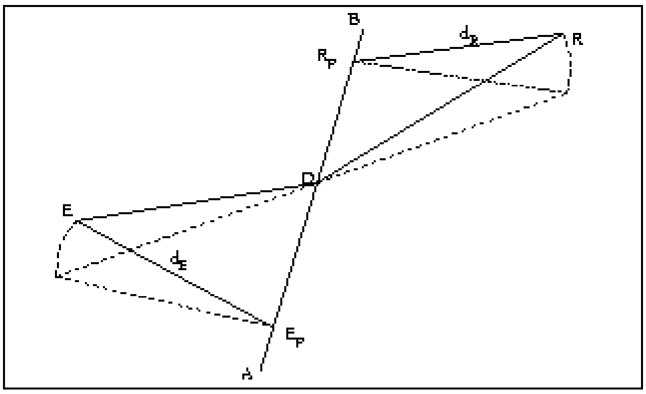

Fig. 1. Analytical Solution for Computing a Path with One Diffraction Point

In 3D, the search for general paths containing both reflection and diffraction points is an open problem, since only a partial numerical solution is known [2]. The problem is that it seems to be impossible to propose an analytical solution for the search of *n* consecutive diffraction points. So, a numerical algorithm is generally used in order to find paths limited to those of the type $R^*D^*R^*$. Authors propose an algorithmic solution, which allows the finding of any paths. This algorithm is a recursive one, based on the analytical solution of a one-diffraction point path. This well-known solution allows to compute the diffraction point *D* on the edge A, in order for *EDR* to be a propagation path with respect to the extended Fermat principle proposed by Keller [4] (see Fig 1). With a parametric coordinate system on the edge *AB*, the position of the diffraction point is known by its parameter *t* as in (1), where t_E (resp. t_R) denotes the parametric coordinate of the point E_p (resp. R_p) which results of the projection of *E* (resp. *R*) on the edge *AB*, and where d_E (resp. d_R) is the length of the vector EE_p (resp. RR_p).

$$t = \frac{t_E \cdot d_R + t_R \cdot d_E}{d_E + d_R} \quad (1)$$

By use of the mirror image method, one can easily find a path of the type R^*DR^*.

1.2. Recursive Algorithm for 2 Diffraction Paths

In order to compute the path between two points with two diffraction points on two edges, we propose a recursive solution based on the geometrical understanding of the Newton-Raphson method [4]. The idea is to decompose this problem into two interlaced ones, solved by the precedent solution seen in 1.1. Practically, the problem is to search the points D_1 and D_2, which are respectively on the edges A_1 and B_1, in order to make a valid path ED_1D_2R. We first search for E_1, the projected point *E* on the edge A_1. Then we compute the diffraction point R_1 on A_2, which form a path E_1R_1R. Then, in a same way we can compute E_2, the diffraction point, which forms a path EE_2R_1. Recursively, we compute the two point series (E_i) and (R_i). When these series become stationary, then we can consider that we have found the two searched diffraction points (demonstration of this theorem can be found in [5]).

1.3. Algorithmic Solution for Any Path

The solution presented in the previous section can be easily extended to path containing any number of successive diffraction points. In fact, it can be extended to all the possible paths, *i.e.* those of type $\{R|D\}^*$. This leads to the following algorithm:

```
Function ComputePath (E, R: Point; n:integer; A: array [1..n] of Object) : array of Point
  LET T_k : array [2..(n-1)] of Point
  LET P_i : array [1..n] of Point
  LET P_i+1 : array [1..n] of Point

  IF A[1] is an edge THEN
        Pi+1 [1] = Projection of E under edge A[1]
        DO
              Pi[1] = Pi+1 [1]
              (T[2], ..., T[n-1], P_i+1[n]) = ComputePath (P_i[1], R, n-1, (A[2],..., A[n]))
              (P_i+1[1],...,P_i+1[n-1])= ComputePath (E, P_i+1[n], n-1, (A[1],..., A[n-1]))
        WHILE P_i [1] <> P_i+1 [1]
  ELSE
        LET E_p = Symmetric Point of E / A[1]
        (P_i[2], ..., P_i[n]) = ComputePath (E_p, R, n-1, (A[2],..., A[n]))
        P_i[1]=Intersection Point of E_pP_i[2] and face A[1]
  ENDIF
  RETURN Pi
END
```

Like in section 1.1., we extend the algorithm which computes any path containing any number of successive diffraction points with the technique of mirroring a source point. This explains the conditional in the previous algorithm. In the case when the first Object is a face, then we compute such a mirror source point in order to compute the sub path. In the other case, the first Object is an edge, and so we have to search for a diffraction point. This is done by using an extended version of the algorithm presented in section 1.2.

2. OPTIMIZATIONS

The new algorithm we described in the previous section allows to compute all the possible paths in a 3D environment. This implies that we virtually get a very large number of potential paths, in which only a few one are really interesting for the estimation of the electromagnetic attenuation received at the point R. So, it appears important to reduce this set of potential paths, as taking into account any of those which are of interest. For this we propose two optimizations: the first one is based on a geometrical criterion, and the second one derives from a physical law.

2.1. Geometrical Optimization

This first criterion is based on the remark that the point that follows a reflection point in a path cannot belong to the half space which is behind the reflection face. This very simple formulation allows to limit the number average of possible paths by 2 when we add a level of reflection or diffraction. So, it leads to an optimization equal to 2^{n-1}, where n is the number of reflection or diffraction points.

In order to implement this optimization, it is important to remark how the list of edges and faces are scanned for testing all the possible paths. With a classical implementation, it consists in an algorithm for computing all the ordered set of *p* edges and *q* faces by computing all the non-ordered set of *p* edges and *q* faces. For using this geometrical optimization, one may rewrite such an algorithm in a recursive way. In fact, we must work directly with the ordered sets, else we cannot early stop the bad computations [5].

2.2. Physical Optimization

This optimization is based on a statistical law, which is due to the work of Pousset [8]. This law is obtained after the study of the diffraction phenomenon not only on a single obstacle but also on several. The retained approach is statistical and enables laws of variation of loss according to the number of successive diffractions in different configurations to be defined. The model used here is inspired by Luebbers [6], for the dielectric aspect of the wedges, and by J.B.Andersen [7] mentioning « slope diffraction ».

The simulations carried out with this model were made on profiles where the wedges were either perfectly conductive or dielectric (ε_r = 8 and σ = 0.003S/m) and for which the geometric parameters such as the position, the height and the opening angle of the obstacles varied randomly on a range fixed according to the configuration. We were placed in small and micro cellular configurations, with the height of the receiver *Hr* fixed at *1.5m*.

A detailed statistical study has been realized on a several hundred terrain profiles per configuration. Firstly, it has been noted that among all the paths existing for a radio link, there exists a particular path which gives roughly the final result. In the following, this path is called the major path. Secondly, the study has shown that whatever the number of successive diffractions, the diffraction loss distributions follows a Gaussian rule, whatever the configuration is. Moreover, for every configuration, the average and the standard deviation of the total loss are close to these due to the major path. Thus, we can consider only this type of path that presents simple or multiple diffractions. After analysis, several points must be noted:

- Whatever the configuration and the frequency are, the standard deviations of the simple or multiple diffraction distributions are quasi constant and close to 9dB. An explanation might be that, in general, the major paths are near the shadow boundaries of the profile.

- A simple law allows to forecastthe average of the multiple diffraction losses A_{np} due to the major paths. This one depends on the number of successive diffractions *np* and on the average loss A_1 due to a virtual obstacle. This obstacle owns a height and an opening angle equal to the average height and opening angle respectively, of all the obstacles of the radio link:

$$A_{np} = \frac{n+1}{2} A_1 \quad (2)$$

Based on this statistical law, we can make an important optimization. We know that, statistically, a path containing *n* diffraction points may produce an attenuation of A_1 more than a path with only *n-1* diffraction points. So, by searching for the path in an increasing number of diffraction points, we can stop the computation when a path with *n* diffraction points produces an attenuation higher than all the possible attenuation produced by paths containing more than *n* diffraction points.

3. PERFORMANCE TESTS

In this section, the performances in computation time and in accuracy of our model relatively to these optimizations are evaluated. A set of ten radio links has been chosen with care for the tests of the models.
A statistical comparison has shown that the accuracy of the 3D UTD model is quasi similar to those of the two optimized models. More precisely, the average deviation between the 3D UTD model and the 3D UTD models optimized physically or geometrically is less than 1.5 dB; the standard deviation is lower than 2 dB.
The performances of the optimized 3D UTD models in computation time have been evaluated. In a first time, we have taken into account the diffraction phenomenon only; so the physical optimization is evaluated. In a second time, we have considered the reflection phenomenon, which is associated to the geometrical optimization.
After analysis, for the two cases it has been observed that:

- The physical optimization reduces the computation time of the 3D UTD model of 90%;
- The geometrical optimization reduces the computation time of the 3D UTD model of 50%.

For the radio coverage prediction, the association of the two optimizations is considered. In this case, a reduction rate roughly equal to 60% is obtained for the computation time. This result is explained by the following observation: for some radio links it does not exist any major path, so the physical optimization is not efficient.

4. CONCLUSION

A solution to the problem of computing the wave propagation in a 3D environment has been proposed. We have proposed a new algorithm, which allows finding all the paths containing diffractions and reflections in any order. Then we have suggested two optimizations easy to implement. These three news points are tested, and some results have been presented. We have observed, in a few ten radio links, that the geometrical and the physical optimizations are as accurate as the classical 3D UTD model. Moreover, these optimizations considerably reduce the computation time of the model (90% for the physical optimization and 50% for the geometrical optimization). For a radio coverage prediction, the reduction in computation time is roughly equal to 60%.
Nevertheless, for future works, it is important to test these models on more cases.

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