# Reflection on curved surfaces in a 2.5D ray-tracing method for electromagnetic waves exposure prediction in urban areas

***Nicolas Noé***[1] and ***François Gaudaire***[2]

[1] CSTB, 11 rue Henri Picherit 44000 Nantes, France, nicolas.noe@cstb.fr

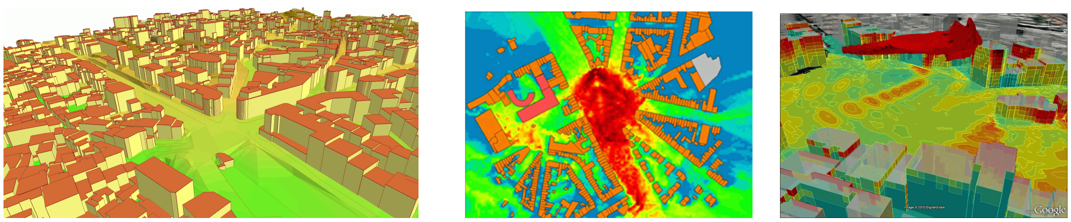
[2] CSTB, 24 rue Joseph Fourier 38400 Saint-Martin-d'Hères, France, francois.gaudaire@cstb.fr

## Abstract

Asymptotic methods are commonly used to predict exposure to electromagnetic waves in large environments such as urban areas. Specifically 2D beam-tracing is a very efficient solution in case of GIS 2.5D environments. Nevertheless taking into account reflection on curved vertical walls or curved ground in such methods is not straightforward. Indeed curved surfaces are mostly described as meshes and lead to artificial shadowing and inaccurate electric field estimation. We explain here how to avoid such problems without modifying existing geometry by using normal interpolation in a generalized beam-tracing technique, and present results for some real cases.

## 1 Introduction

Electromagnetic waves exposure to mobile phone emitters in urban areas is mainly simulated using asymptotic technics such as ray-tracing, since exact numerical methods such as FDTD or BEM would be too time and memory consuming for areas as big as a few km$^2$. Geometric input mostly come from GIS (Geographic Information Systems) with a precision of about 1m: this suits asymptotic methods where details must be rougher than a few wavelengths (lower than 30cm for GSM). Furthermore most of GIS input is 2.5D data (terrain lines are 2D lines with altitudes, buildings are 2D lines with height, see figure 1(a)). Hence 2D algorithms can be used to solve the corresponding 3D problem without quality loss (figures 1(b) and 1(c)).



(a) 3D view of a 2.5D model of an urban area (b) Ground map of electric field (c) 3D map of electric field

Figure 1: Electromagnetic waves exposure computed on 2.5D models of urban areas

## 2 A specific 2.5D algorithm

Asymptotic methods use a geometric solver to find paths from emitters to receivers, solving Fermat's principal (i.e. specular reflections on surfaces and diffraction by edges with the Geometric Theory of Diffraction [1], figures 2(a) and 2(b)) and a physical solver to compute electric field at receiver from these contributions.

### 2.1 2D beam-tracing

In 2.5D geometry walls are vertical surfaces, and a specular reflection on a vertical surface is still specular projected on the horizontal plane. Furthermore diffraction by horizontal edges (top of buildings) is almost a

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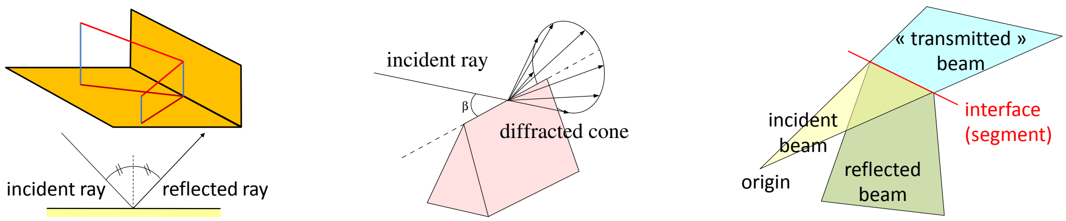
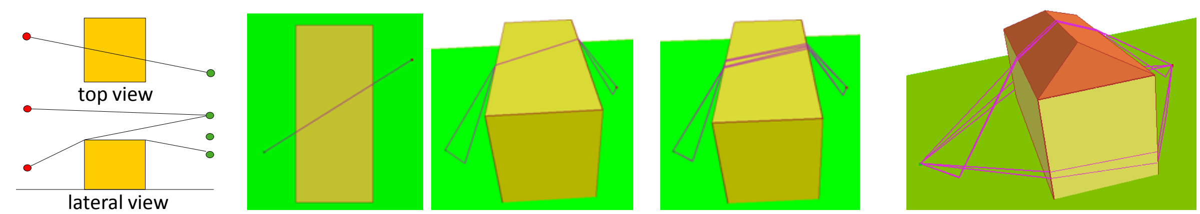



(a) specular reflection (b) Geometrical Theory of Diffraction (GTD) (c) 2D beam-tracing

Figure 2: 2D beam-tracing

straight line when projected. As a consequence computing paths in the horizontal plane solves the problem [2]. Beams (angular sectors) are shot from emitters (figure 2(c)) and are split by wall segments: one part is specularly reflected, another part is “transmitted”. Whole beams trees are computed and receivers are located into them. Then exact point-to-point 2D paths are computed using image-source technique.

## 2.2 Computation of 3D paths



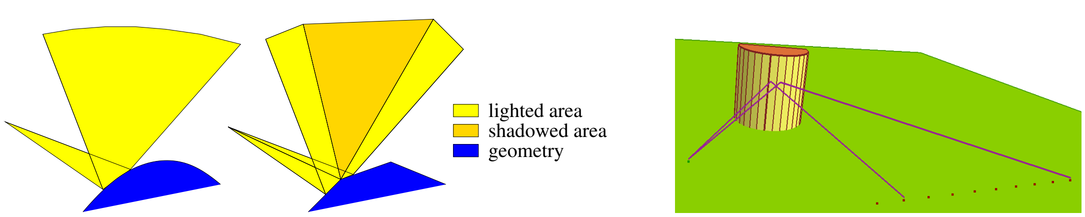

(a) top & lateral views (b) 2D path (c) 3D paths (d) 3D paths & GTD (e) Roof and lateral diffraction

Figure 3: 2D & 3D paths

3D paths are computed from 2D paths using convex envelop technique. Depending on heights of emitter, obstacles and receiver, “transmission” is transformed into direct view or diffraction (figure 3(a)). Reflections on the ground are added in the lateral view with images sources (figure 3(c)). Exact diffraction point position according to GTD is solved using optimization (figure 3(d)). Diffraction from vertical edges can be added as second order emitters, as these edges transform into a point in the 2D plane. A simple case is displayed on figure 3(e). This gives a solution almost equivalent to the 3D solution and transfers can be computed.

# 3 Reflection on curved vertical surfaces

## 3.1 Problem

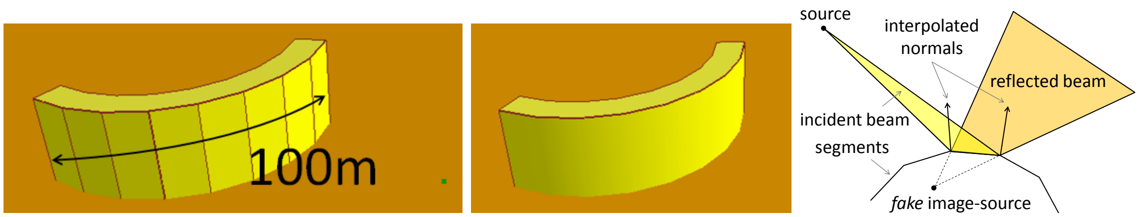



(a) artificial shadowing effect (b) missing reflected contributions

Figure 4: Curved surfaces represented as straight segments

In GIS data curved buildings are described as sets of straight segments. The trouble is that contrary to BEM using asymptotic methods on meshed geometry does not converge to the curved geometry solution [3]. The overall energy is correct but the local behaviour is erratic: there are artificially shadowed areas (figure 4(a)) leading to missing reflected contributions (figure 4(b)). Furthermore the attenuation of the wave is incorrect, not taking into account surface curvature.

### 3.2 Geometrical solution with interpolated normals




(a) curved building with straight segments (b) smoothed building (c) smooth beam reflection

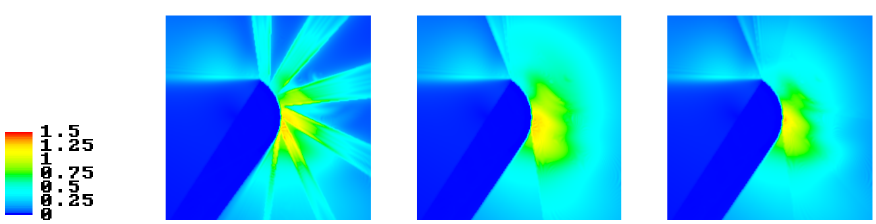
Figure 5: Using interpolated normals for reflection on curved vertical surfaces given as straight edges

A solution is to use interpolated normals: normals are averaged at nodes and linearly interpolated between them. From a curved building described with straight segments (figure 5(a)), it gives the illusion of a curved surface (figure 5(b)). This smoothing is automatically done when the angle between two adjacent segments is small with no need of input data modification. Since beam-tracing is 2D, the reflected beam still converges into a point (fake image-source) and the algorithm is still valid (figure 5(c)).

### 3.3 Computation of wave attenuation

In case of reflection on flat surfaces, the wave attenuation in 3D is $1/r$, $r$ being the length of the path. In case of reflection on curved surfaces it is $\sqrt{d\omega/dS}$, $d\omega$ being the solid angle shot from the source and $dS$ the surface of the wavefront at the receiver. For 2D beams we compute the ratio of the apertures of the beam at the source and at the receiver (as for cylindric waves). The 3D attenuation (spherical waves) can be computed from the 2D one using the angle between the outgoing path at the source and the vertical axis.

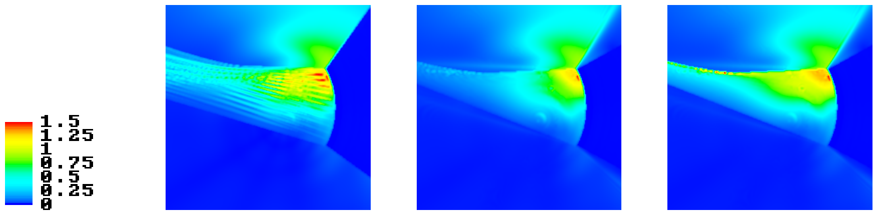
### 3.4 Results




(a) scale (V/m) (b) flat segments (c) smoothed normals (d) smoothed normals and corrected attenuation

Figure 6: Reflection on a convex curved vertical wall, total electric field (direct, reflected and diffracted)

Results are first displayed for a source on the convex side of the building: flat solution (figure 6(b)) with its shadowing effects, smoothed solution with $1/r$ attenuation (figure 6(c)), and with corrected attenuation (figure 6(d)). The latter is continuous and takes into account attenuation of the wave due to the curvature.

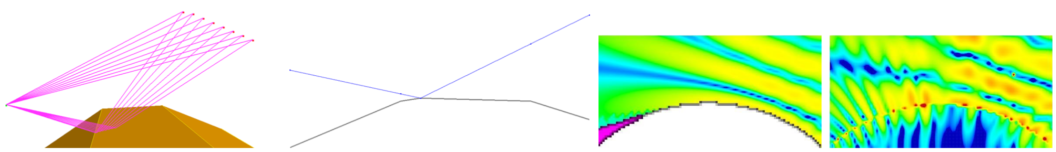



(a) scale (V/m) (b) flat segments (c) smoothed normals (d) smoothed normals and corrected attenuation

Figure 7: Reflection on a concave curved vertical wall, total electric field (direct, reflected and diffracted)

For a source on the concave side results are different: the flat solution (figure 7(b)) does have extra reflections (instead of missing ones). It clearly differs from the smoothed solution (figure 7(c) and 7(d)) far from the surface. Notice that the fake image-source is in the reflected area, leading to two reflected beams.

## 4 Reflection on curved ground



(a) ground reflections (b) added reflected point (c) asymptotic method vs BEM reference

The same reflection problem occurs for ground reflection, since it is described with terrain lines. There are often missing ground reflections, as on figure 8(a) where no reflection on the flat ground exists. To overcome this problem a cubic interpolation of the ground in the lateral view is performed, hence leading to a $C^1$ ground curve. The reflection point is found using optimization technique (figure 8(b)), slightly modifying the ground shape. Convincing comparisons of this technique with BEM is displayed on figure 8(c).

## 5 Conclusion

This 2D beam-tracing technique gives realistic results (compared to reference solution) for reflection on curved surfaces even if they are discretized. Furthermore it improves stability of the results against input data, since two different meshes would lead to the same result.

## 6 References

1. R. G. Kouyoumjian and P. H. Pathak, "A uniform geometrical theory of diffraction for an edge in a perfectly conducting surface", *Proceedings of the IEEE*, 1974, 62(11), pp. 1448-1461.

2. F. A. Alves, M. R. M. L. Albuquerque, S. G. Silva and A. G. d'Assunção, "Using Efficient Ray-Tracing Techniques to Predict Propagation losses in Indoor Environments", *Microwave and Optical Technology Letters*, 2007, 49(4), pp. 854-858.

3. N. Noé, F. Gaudaire, P. Jean and M. Vermet, "A General Ray-Tracing Solution to Reflection on Curved Surfaces and Diffraction by their Bounding Edges", *Proceedings of the 9th International Conference on Theoretical and Computational Acoustics*, Dresden, GE, 2009, pp. 225-234.