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Lamppost and panel scattering compared to building reflection and diffraction

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1. Introduction

Accurate and efficient coverage and propagation prediction models in urban environments are of major interest in the case of small and micro-cells which are deployed to support high traffic in cities. The development of coverage prediction models and propagation simulations usually require a good understanding of the propagation phenomena. Also required is a good set of measurements to validate the models. In coverage prediction models for urban areas the propagation phenomena frequently considered are [COST231]:

- multiple forward scattering and diffraction in most empirical models or
- specular reflection from building walls, diffraction by building corners and multiple diffraction over the rooftops in models which tends to be more deterministic.

Scattering by individual urban features like lamp post, traffic lights, trees, fences, metallic signs, vehicles, etc. are rarely considered. Their influences have not been extensively documented, although they are sometimes mentioned to explain the discrepancies between a model and measurements. As it is difficult and costly to include these special urban features in a database, their effects could be either disregarded or included in a statistical way. In any case, the order of magnitude of these contributions are of interest.

Using a simple geometry, this paper aims to provide a numerical comparison between several propagation phenomena which could occur in an urban environment, namely:

- single diffraction around a corner,
- specular reflection and single diffraction around an intersection (4 corners),
- scattering by a metallic post (cylinder),
- scattering by a finite plate (panel), and
- over-rooftop diffraction modeled by a knife-edge diffraction as in most current deterministic coverage prediction models.

To validate the conclusion found from the investigation of the simple geometry, a comparison with measurements and predictions including the effect of lampposts are shown. The environment was carefully chosen to be as close as possible to the simple geometry investigated (4-corner intersection).

The theoretical investigation of the simple geometry is shown in Section 2. The application to a real environment and the comparison with measurements are presented in Section 3. Lastly, Section 4 concludes this brief investigation.

2. Theoretical investigation

This section presents the scattering of the spherical wave emanating from the transmitter Tx and reaching the observation segment route_1 in Figure 1. Three types of scattering are considered

- 1- single diffraction around corner1. The wedge is considered as perfectly absorbing according to [Felsen73]. The diffraction formula are given below
- 2- scattering of a perfectly conducting infinitely high circular cylinder centered at corner 3. Two radii are considered: $r=7\text{cm}$ and 15cm .

- 3- scattering by a perfectly conducting finite panel centered at corner 3. The orientation of the panel is such that the normal to the surface of the panel makes a 45° angle with the x axis. Two panel sizes are considered: A=1x1m² and 2x2m²

The diffraction around corner1 reaching the receiving antenna Rx (Fig. 1) can be calculated using the following expression:

$$E_r = E_0(\rho') D \sqrt{\frac{\rho'}{\rho(\rho + \rho')}} e^{-jk\rho} \quad (1)$$

where D is the diffraction coefficient, k is the free space wave number, E_0 is the free space field strength, ρ' and ρ are defined in Figure 1.

The Perfectly Absorbing Wedge (PAW) diffraction can be calculated using [Felsen73]:

$$D = \frac{e^{-j\pi/4}}{\sqrt{2\pi k}} \left[\frac{1}{\pi - |\phi - \phi'|} + \frac{1}{\pi + |\phi - \phi'|} \right] - \frac{\sqrt{L} \operatorname{sgn}(\pi - |\phi - \phi'|)}{2} \left[F_T(\xi) - \frac{e^{-j\pi/4}}{\xi \sqrt{2\pi}} \right] \quad (2)$$

Where $F_T(\xi)$ is given by:

$$F_T(\xi) = \frac{e^{-j\pi/4}}{\sqrt{2\pi\xi}} F(-2\xi^2)$$

with $F(x)$ is the transition function

$$F(x) = 2j \sqrt{x} e^{jx} \int_{\sqrt{x}}^{\infty} e^{-j\tau^2} d\tau \quad (3)$$

and:

$$\xi = \sqrt{kL} \left| \sin \left(\frac{\pi - |\phi - \phi'|}{2} \right) \right| \quad L = \frac{\rho\rho'}{\rho + \rho'}$$

Since we are mainly interested here in orders of magnitude, the most simple expressions from the Geometrical Optic (GO) are used to compute the cylinder scattering. Although not shown here these GO contributions were found to accurately approximate the total scattering in the backward direction of the cylinder. The geometric optic contributions were computed according to the following equation:

$$E_r = -E_0(\rho') \sqrt{\frac{\rho'}{\rho(\rho + \rho')}} \sqrt{\frac{\cos(\theta_i)r}{2}} e^{-jk\rho} \quad (4)$$

where ρ' (ρ) is the distance between the reflection point on the cylinder and the transmitter (receiver). θ_i is the incidence angle on the cylinder, i. e., the angle between the incident or reflected ray and the normal on the cylinder at the reflection point, and r is the radius of the cylinder. Equation (4) was derived from the more general expression of the reflection by a curved surface found in [Balanis89]. The simplification of the general expression took advantage of the fact that ρ' and $\rho \gg r$.

The scattering of the panel is given by to the bistatic radar equation:

$$E_r = -E_0(\rho') \frac{1}{2k\rho\rho'} \sqrt{\frac{2\cos(\theta_i)\cos(\theta_s)A}{\pi}} e^{-jk\rho} \quad (5)$$

where ρ' (ρ) is the distance between the center of the panel and the transmitter (receiver). θ_i (θ_s) is the incidence (scattering) angle on the panel, i. e., the angle between the incident (scattered) ray and the normal on the panel. A is the surface of the panel.

We assume a transmitter field of 1[V/m]. Thus, $E_0(\rho')=1/(2k\rho')$ and the path loss is $L = 20\log(E_r)$. The frequency in all the simulations presented in this paper is 1800 MHz.

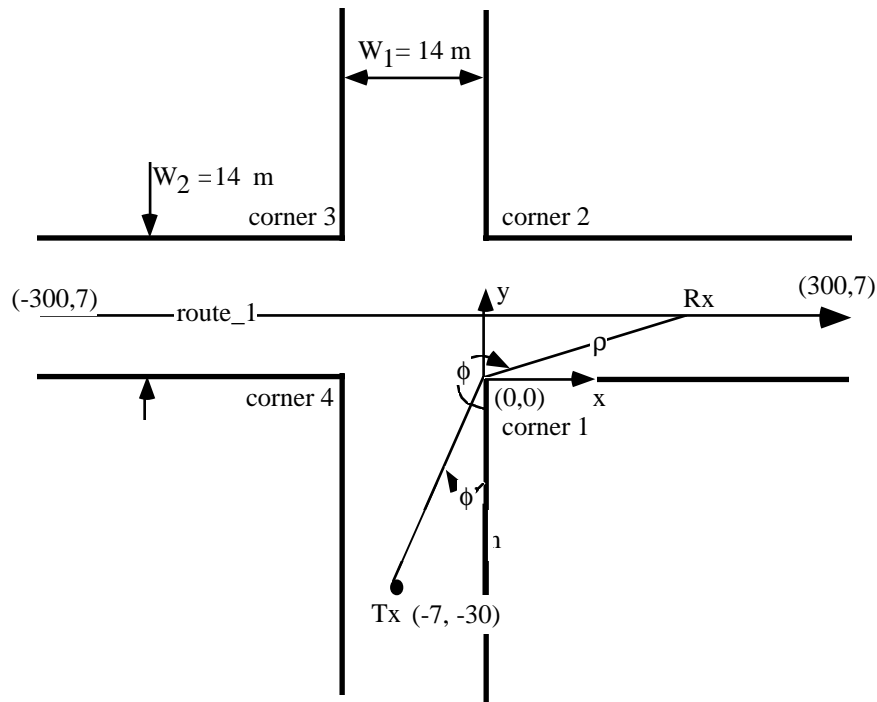


Figure 1 Geometry and notation for an intersection

Figure 2 shows the comparisons between the above listed single element scatterers. For comparison, the propagation in the 4-corner intersection (Figure 1) is also shown. In the 4-corner propagation up to 9 reflections, or up to 8 reflections and a single diffraction per path were considered. The diffraction here was also computed using the perfectly absorbing wedge diffraction. The electric relative permittivity and the conductivity of the building walls have been chosen equal to $\epsilon_r = 5$ and $\sigma = 10^{-4}$ [S/m].

From Figure 2 the following observations can be drawn:

- 1- The 4-corner propagation is about 10 dB higher than the single corner diffraction. As shown in Figure 3, the singly diffracted rays account only for part of the energy reaching the receiver in the 4-corner scenario. The remaining part of the energy reaching the receiver is due to rays which are multiply reflected and singly diffracted.
- 2- Few meters after turning from the LOS to NLOS, the scattering by a relatively large cylinder (diameter 30 cm) becomes 10 dB larger than the diffraction by a single building.
- 3- About 50 meters after turning from the LOS to NLOS, the scattering by a relatively large cylinder (diameter 30 cm) becomes comparable to the 4-corner propagation.
- 4- About 50 meters after turning from the LOS to NLOS, the scattering by a relatively large panel (surface $A=2 \times 2 \text{m}^2$) becomes comparable to the diffraction by a single corner but remains 10 dB lower than the 4-corner propagation

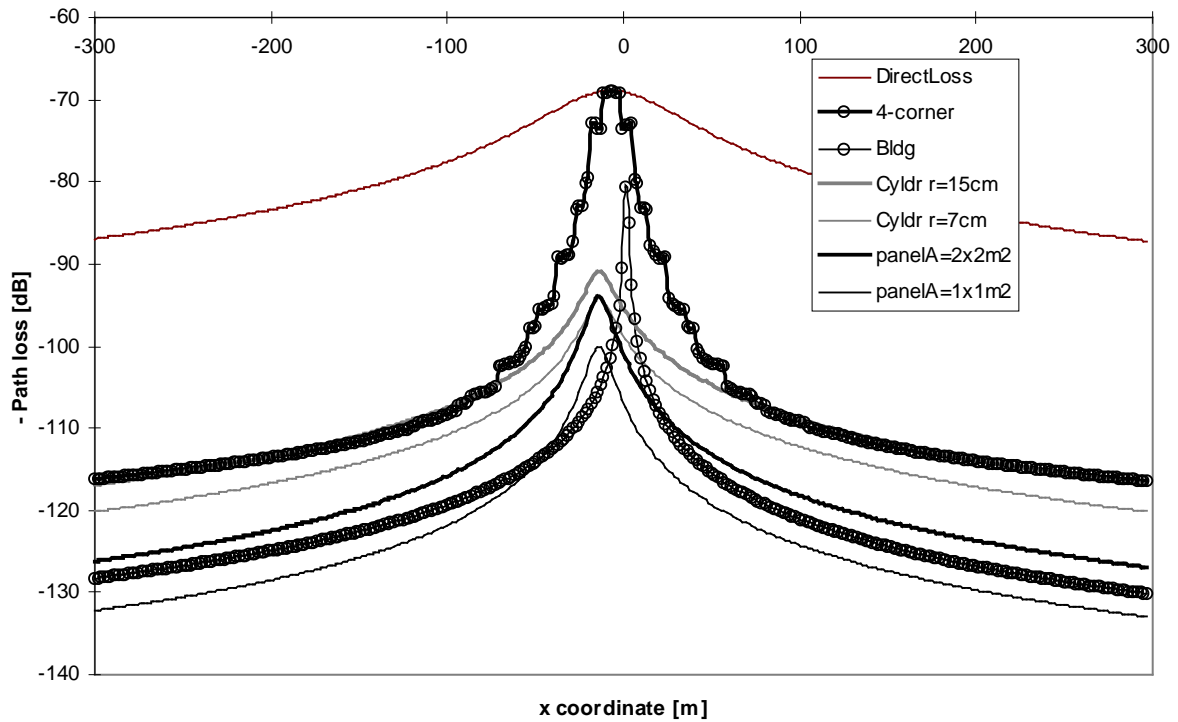


Figure 2 Comparison between: 1) single diffraction around corner1 (Figure 1), scattering of a perfectly conducting infinitely high circular cylinder centered at corner3 , 2) scattering by a perfectly conducting panel centered at corner 3, 4) 4-corner propagation.

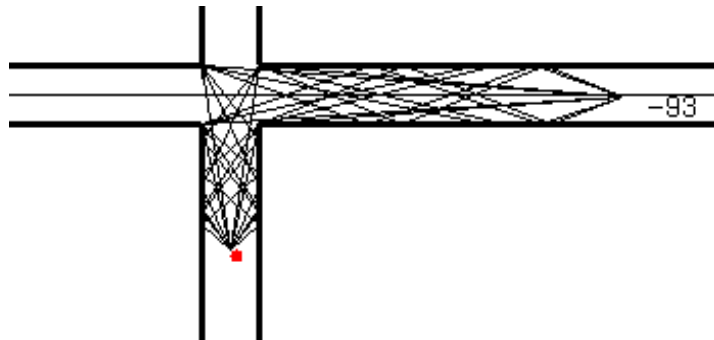


Figure 3 Multiple reflections and single diffraction lead to the guiding effect of the street canyon.

We expect from point 1 above that neglecting the diffraction by cylinders such as lampposts, as usually done in deterministic approaches, has small effects on the propagation predictions in dense urban environments. In fact in such environments the guiding effect of the street canyon is strong enough, which minimizes the effect of neglecting other scatterers located outside building. In an area with a low density of buildings, the effects of isolated scatterers will dominate the propagation. From point 3 above the scattering by panels will be important only in areas where there are almost no buildings.

In many prediction models which account for the propagation in the vertical plane, the vertical cut of each building is replaced by a single knife edge placed at the center of the building (Figure 4). The evaluation of the accuracy of the knife edge approximation is beyond the scope of this paper. However, it is of interest to know how the predictions using the knife edge diffraction approximation compare with the various types of propagation presented above. Thus we considered a row of buildings placed as shown in Figure 4. The height of the buildings is assumed to be 12 m. The over rooftop contribution was computed assuming a knife edge placed at the center of the vertical profile of the row. The diffraction was computed using the absorbing screen formulae which could be found for instance in [Andersen94].

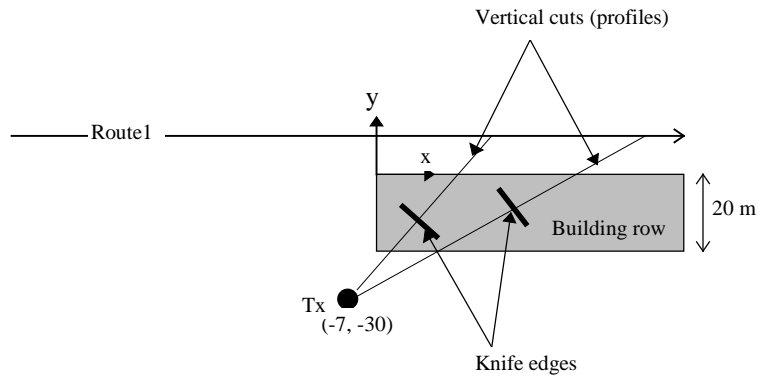


Figure 4 Over rooftop diffraction over a row of buildings.

Comparison between 1) the over rooftop contribution for three transmitter heights: 6, 10 and 14 m, 2) the diffraction by corner1 (Figure 1) and 3) the propagation in the 4-corner intersection are shown in Figure 5. From Figure 5 it can be seen that starting from about 30 meters after tuning from the LOS to NLOS the over rooftop contribution, even for a low transmitter, is higher than the energy propagating in the horizontal plane in the 4-corner intersection scenario. The over rooftop diffraction exceeds the horizontal contribution by about 10 dB for a transmitter height of 14 m. In fact, since a knife edge is located at the middle of the building in the vertical plane, the diffraction angles involved in the over roof top diffraction are larger, thus more favorable, than those involved in the diffraction around the corner.

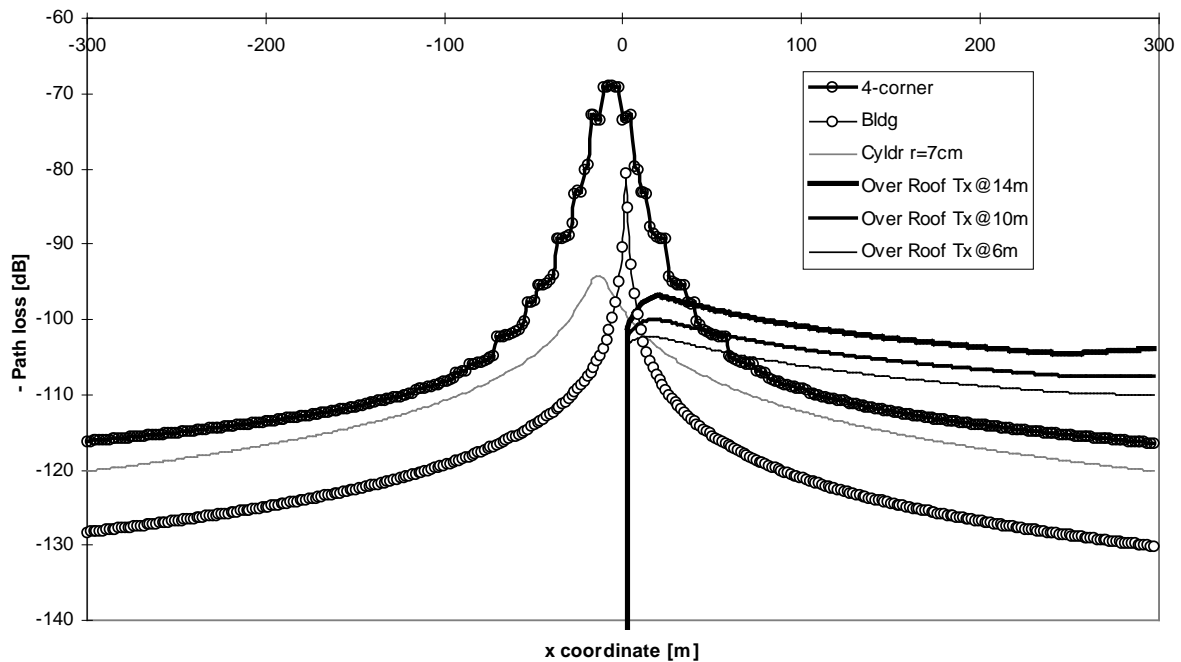


Figure 5 Comparison between 1) the over rooftop contribution for three transmitter heights: 6, 10 and 14 m, 2) the diffraction by corner1 (Figure 1) and the 3) propagation in the 4-corner intersection

3. Application to a real environment and comparison with measurements

In the previous section a theoretical investigation of the influence of isolated scatterers showed that lamppost scattering could be the dominant propagation phenomenon in some situations, namely in areas with low density

of buildings. In order to validate this conclusion and evaluate the influence of the lamppost scattering in a real city, this section presents comparisons between measurements performed in Fribourg and ray tracing predictions that include the effects of lamppost scattering.

The ray tracing program account for specular reflection by building walls and single diffraction by building corners. As in the 4-corner scenario presented in sect. 2, up to 9 reflections, or up to 8 reflections and a single diffraction per path were considered. In the predictions shown in this section the heuristic extension of the UTD [Luebbbers84] was used to account for the diffraction instead of the PAW. In [Rizk97], it was shown that both formulations lead to similar prediction results when applied in a real environment. The over rooftop contribution was considered to be negligible due to the geometry. In fact, a more realistic approximation of the building profile than the approach used in sect 2, will involve double diffraction in the profile plane thus leading to higher attenuation than the lateral (around building) contributions. In sect 2 we used a simple approach in order to mimic what is usually used in many vertical plane prediction models.

The scattering of lampposts was accounted for as follows. From equation 4 it is observed that the scattered field of an infinite cylinder has the same dependency on distance as the diffraction by a wedge. Also, similarly to a wedge, the cylinder diffracts in all directions. Thus the cylinders were introduced in the program as a diffracting source radiating according to equation 4. Therefore, all direct and reflected rays hitting a cylinder are scattered in all directions. These rays can either reach the receiver directly or after multiple reflections. An example of a ray diffracted by a cylinder then doubly reflected before reaching the receiver is shown in Figure 6. The rays were added in power. When lampposts are not considered in the predictions, the power summing was found in [Erceg94] to be a reasonable approximation of the phase summing at 1800MHz and relatively small distance from the source as in our example here. At this stage of our research we are not able to determine the error due to the power summing when cylinder scattering is accounted for. In fact, the coherent summing of the rays scattered by lampposts was not possible in the current implementation as the exact location of the reflection point on the cylinder was not computed. The latter is needed to compute the phase of each scattered ray. However, the power sum is expected to be an upper bound of the actual field.

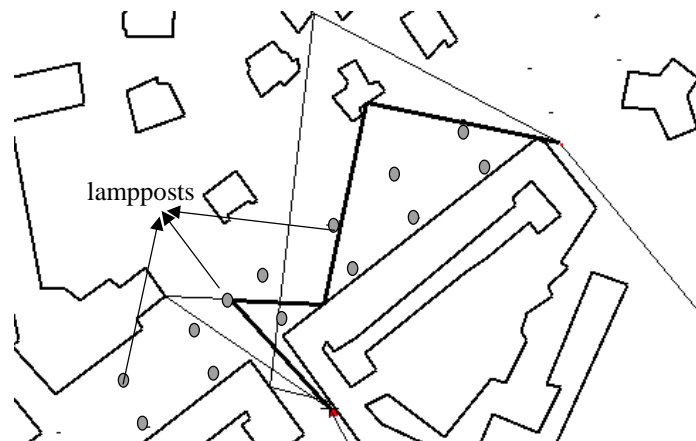


Figure 6 An example of a ray diffracted by a cylinder then doubly reflected before reaching the receiver

The map of the area considered in our prediction is shown in Figure 7. The four crosses indicate the position of the sources (transmitters) and the segments in thin lines indicate the measurement routes. The area considered is characterized by an irregular layout of 3-4 stories concrete buildings and some traffic on Perolles St. (a commercial street). The measurement frequency was the same as the one used in the theoretical investigation in sect. 2, i. e., 1800 MHz. Two rows of lampposts (radius 7cm) were added in Perolles St. The lampposts were placed at interval of 30 m. In order to maximize the effects of lamppost scattering, the location of the lampposts was chosen such that all the transmitters are in the line of sight of at least one lamppost. An investigation of the propagation in this environment was already performed in [Wagen94]. The study in [Wagen94] did not focus on the scattering by isolated elements.

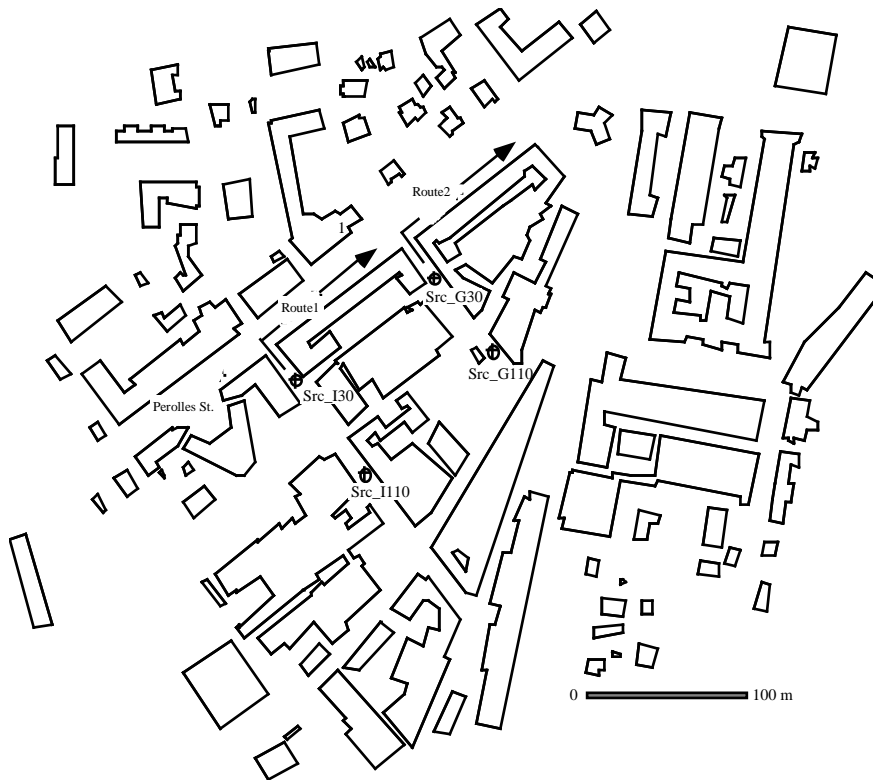


Figure 7 Map of Fribourg as considered in the predictions. The crosses indicate the position of the sources (transmitters) and the two segments in thin line indicate the measurement routes. The arrows on the two observation segments indicate the direction driven

Figure 8 and Figure 9 show comparisons between 1) measurements, 2) the ray tracing predictions *without* lampposts and 3) the ray tracing predictions *with* lampposts on route_1 and 2 for the two transmitter locations Src_I30 and Src_G30, respectively. The two locations were chosen to investigate the influence of the missing buildings in the upper side of route 2.

On route_1, where the neighboring buildings form a 4-corner intersection (Figure 7), adding the effects of lampposts affects slightly the predictions. This is in accordance with the theoretical investigation in sect. 2. On route_2 (Figure 7) the guiding effect of the street canyon is weakened because of the missing buildings in the upper side of route2. Thus, the scattering by scatterers outside buildings become the dominant phenomena. Here the lamppost scattering dominates over the reflection and diffraction of buildings by an average of 6 dB, starting from distance 70 m on route_2. The overall agreement with measurements is only slightly improved when the effect of lampposts is added. For instance, the smooth drop in the measurements on route_2 when turning into the NLOS street is not predicted correctly even when the lamppost effects are added.

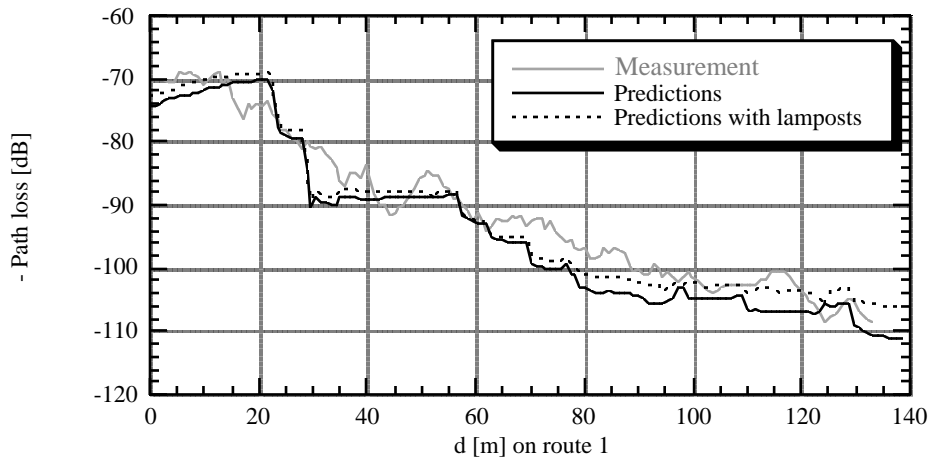


Figure 8 Comparison on route_1 between 1)measurements, 2) the ray tracing predictions without lampposts and 3) the ray tracing predictions with lampposts for the transmitter location Src_I30

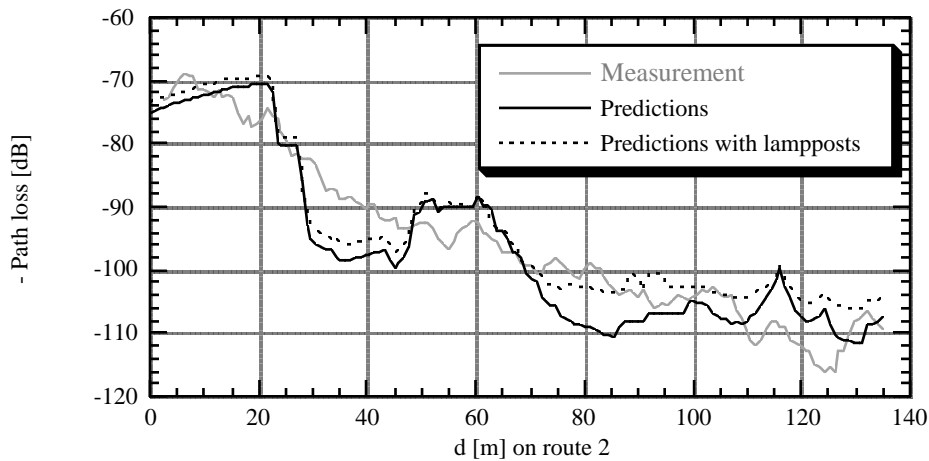


Figure 9 Comparison on route_2 between 1)measurements, 2) the ray tracing predictions without lampposts and 3) the ray tracing predictions with lampposts for the transmitter location Src_G30

4. Conclusions

This investigations roughly compared the contributions of propagation phenomena which are believed to occur frequently in urban mobile radio cells. Our investigation was focused in the non-LOS portion behind a building.

Listing the contributions according to their popularity in the use of coverage prediction models, the following remarks are made:

1. the diffraction over the roof top was shown to dominate far from the corner and therefore far from the base station even when the base station was far below the rooftop. Near the base station however (less than 30 m of the corner), the over rooftop contribution is more than 10 dB below other contributions. The geometry used here, i.e., a single knife edge in the middle of the building portion, aimed at approaching what is used in most coverage prediction models. The knife edge approximation chosen was not intended to lead to an exact solution of the diffraction over a real building.

2. Specular reflections and corner diffraction dominate in general all other contributions near the corner of a building. Specular reflections help the guiding of the energy along the non-LOS streets since they provide about 10 dB more power than the diffraction by a single corner.
3. Scattering by one or several metallic cylinders, such as lamp or traffic posts, can have as much effect as the specular reflections and corner diffraction.
4. Scattering by small finite surface do not dominate although in reality the cumulative effects of several such surfaces could be non-negligible.

Apart from the over rooftop contributions, all the other contributions considered here are in the "horizontal" plane. Since scattering from urban features like lampposts and metallic signs may have rather significant effects, and since these features do not appear in commonly used urban database, it is expected that statistical and/or empirical models having the property of letting some energy "turning" around the corners can be tuned to achieve accurate prediction.

Near the base station (< 200 m in our measurements), the good accuracy of deterministic models based on ray tracing with specular reflection and diffraction is due to the simulation of the guiding effect in the street canyon. This guiding effect may be strong enough in a dense urban environment and thus minimizes the effect of neglecting other scatterers than building walls and corners. However, in areas with low density of buildings, the guiding effect of street layout is expected to be weak and the scattering by isolated elements and/or the over rooftop contributions may dominate the propagation.

These conclusions must be further validated. A better insight would lead to the development of a coverage prediction model which can be easily and accurately tuned using only a small amount of measurements.

5. References

- [COST231] "DIGITAL MOBILE RADIO TOWARDS FUTURE GENERATION SYSTEMS", Final Report COST 231, Editor E. Damosso, Springer Verlag, 1997. Chap. 4: Propagation Prediction Models.
- [Felsen73] Felsen, L. B., and N. Marcuvitz, *Radiation and Scattering of Waves*, Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 1973. Sec. 6.4.
- [Rizk97] Rizk K., Wagen J. F., Gardiol F., "Two Dimensional Ray Tracing Modeling For Propagation Prediction In Microcellular Environments", Accepted for publications in the *IEEE Trans, Veh. Technol.*
- [Balanis89] Balanis, C. A., *Advanced engineering electromagnetism*. Wiley 1989. Sect 13.2.3
- [Luebbers84] Luebbers R., "Finite conductivity uniform GTD versus knife edge diffraction in prediction of propagation path loss," *IEEE Trans. Antennas Propag.*, vol. AP-32, no. 1, pp. 70-76, Jan. 1984.
- [Wagen94] Wagen, J. F., and Rizk, K., "Ray Tracing based prediction of impulse responses in urban microcells", *Proceedings IEEE 44th Vehicular Technology Conference*, Stockholm, Sweden, June 1994.
- [Andersen94] Andersen, J. B., 'Transition zone diffraction by multiple edges', *IEE Proc., Microw. Antennas Propag.*, 1994, 141, (5), pp. 382-384
- [Erceg94] Erceg, V., Rustako, A. J. and Roman R. S. "Diffraction around corners and its effects on the Microcell coverage area in urban and suburban environments at 900 MHz, 2 GHz, and 6 GHz", *IEEE Trans. Trans. Vehic. Technol.*, Vol. 43, No. 3, pp. 762-766, August. 1994.