A Recursive Method For Street Microcell Path Loss Calculations

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Abstract: **A recursive, reciprocal, very simple and computer efficient mathematical method for microcell path loss calculations is suggested. Arbitrary street crossing angles, bent streets with linear sections and transmitter locations close to the street crossing can be modelled.**

1 Introduction

A mathematical method is suggested for path loss calculations along streets surrounded by buildings which are considerably taller than the height of the antennas. The method is recursive, and thus suited for ray or path tracing techniques, where the loss is determined along paths following the different streets. The procedure is not restricted to perpendicular street crossings only, they can have any arbitrary angle. Bent streets with linear segments can also be treated. The method is reciprocal, very computer efficient and simple to use.

First, some basic information is given regarding street orientation and transmitter location. Then, the basic model and a simplified version are given, followed by some examples concerning different street crossing angles, which show how the model can handle these cases by choosing appropriate parameter values.

Thereafter, two methods are suggested on how to model the well-known dual slope behaviour in micro cells. Finally, a simple extension is given by introducing an additional parameter which increases the possibilities to vary the model.

2 Street Orientation

A general model should be able to handle any arbitrary angle θ of the crossing street, or a bent street, as in the examples shown in Fig. 1.

The received signal strength along the perpendicular street *a*, Fig. 1, behaves usually as if the power originates from a hypothetical transmitter located in the proximity of the street crossing, *SC*, while along the line of sight street *c*, the signal of course seems to originate from the actual transmitter *Tx*. The suggested method has these properties for these two cases. Between these two extreme cases, the model generates a continuos path loss as a function of the angle θ. Any arbitrary street orientation, e.g. street *b* in Fig. 1, can thus be considered.

It is also possible to handle the case shown in Fig. 2, where the transmitter is located quite close to the corner.

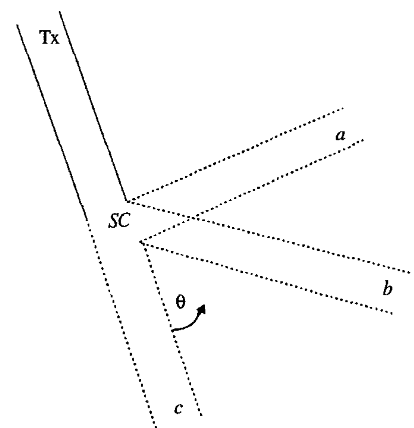

Figure 1 Example of street crossings at different angles θ.

Thus creating an angle which is less than 90 degrees, which is the angle of the street crossing.

3 The Basic Model

The path loss between isotropic antennas is determined by the "illusory" distance d_n and is primarily calculated according to the following well-known expression

$$L_{dB}^{(n)} = 20 \cdot \log\left(\frac{4 \cdot \pi \cdot d_n}{\lambda}\right) \qquad (1)$$

where λ is the wavelength and n the number of sections between the nodal points included in the calculation, see Fig. 3 where $n = j_{max} = 3$.

The "distance" d_n is defined by the recursive expression

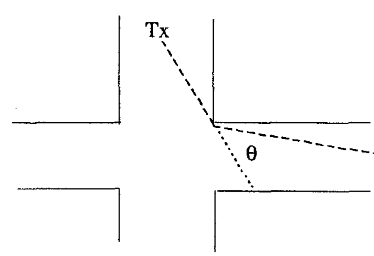

Figure 2 Example of transmitter location in the proximity of the street crossing.

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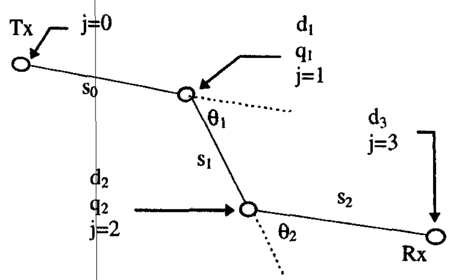

Figure 3 Example of street orientation.

$$\begin{cases} k_j = k_{j-1} + d_{j-1} \cdot q_{j-1} \\ d_j = k_j \cdot s_{j-1} + d_{j-1} \end{cases} \quad (2)$$

with the initial values

$$k_0 = 1 \quad and \quad d_0 = 0 \quad (3)$$

s_j and q_j are described below.

In the example in Fig. 3, the solid line describes the track of the propagating wave between the transmitter, *Tx*, and the receiver, *Rx*. The path changes directions at the nodal points, j=1 and j=2, with the angles θ_1 and θ_2.

The parameter s_j is the physical distance in metres and d_j is the "illusory" distance defined in (2). If the direction of the track is reversed, the calculated path loss will not change, due to that the method is reciprocal.

The number of nodal points can be arbitrary, but at least two.

The parameter q_j determines the angle dependence of the path loss. When q_j =0, no additional loss is introduced. This value should be used for straight streets when θ_j =0. When θ_j =90 degrees, a proper value of q_j is about 0.5-1. q_j should increase continuously when the angle increases.

The following is always valid:

- if qj =0 at the nodal point j, between Tx and Rx, the calculated path loss will not change if that point is removed
- the path loss will not change if a new nodal point is inserted, between *Tx* and *Rx*, and its corresponding q_j value is set to 0

If the distance s_j is constant and equal to 1 metre for all j, then (2) can be simplified to the following expression

$$d_j = d_{j-1} \cdot (2 + q_{j-1}) - d_{j-2} \quad (4)$$

with the initial values

$$d_1 = 1 \quad and \quad d_2 = 2 + q_1 \quad (5)$$

If a path has arbitrary distances, s_j, and new nodal points are inserted along the track, such that:

- the distance between any two adjacent points, s_j, old and new, is equal to 1 metre
- for new nodal points, q_j is set equal to 0
- for old nodal points, q_j remains unchanged

then, the calculated path loss according to (1) will be equal, if either (2) or (4) is used in order to determine d_n. The value of the index n will of course be different for the two cases.

To conclude, the recursive expression (2) can always be applied and gives a reciprocal result. If the distance between every two adjacent calculation points is 1 metre, the simpler expression (4) can be applied.

4 A Basic Example

The path loss is determined by the parameter q_j. The following expression is a very simple approach to model the angle dependence of q_j

$$q_j(\theta_j) = (\theta_j \cdot \frac{q_{90}}{90})^{\nu} \quad (6)$$

where, for simplicity, θ_j is in degrees.

The q value will be 0 when θ_j =0 and equal to the parameter q_{90} when θ_j =90 degrees. ν determines the shape of the function. Expression (6) is just an example on how the angle dependence can be modelled and it is not derived from measurements. A path loss model, including the street angle dependency is described in [1] and [2].

The calculated path loss for a configuration according to Fig. 3, with s_0 =100 metres, s_1=200 metres, θ_1 =90 and θ_2=0, 10 and 90 degrees is displayed in Fig. 4. The parameter values q_{90}=0.5 and ν=1.5 were chosen in (6).

The result in Fig. 4, shows that the calculated increase of the loss after the 90 degrees corners is within the range which is expected and known from several published meas-

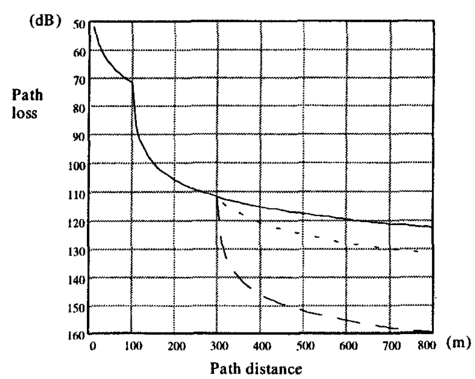

Figure 4 Example of calculated path loss. θ_2=*0*, solid line, θ_2=10, dotted line, and θ_2=90 degrees, dashed line.

urements at the actual wave length, λ=0.33 metres, e.g. [3]. It also demonstrates the ability of the model to handle a bent street with two linear segments, the case when θ_l =10 degrees.

5 Dual Slope Modelling

It is well known that the distance dependence of the path loss generally has a double slope behaviour [3,4]. First, typically the slope is around 2, as for free space propagation. Then, after a certain breakpoint distance, x_{brk}, the slope increases to a greater value, e.g. 4. Two methods will be given below on how to model this behaviour.

For the first method, the following function is introduced

$$D(x) = \begin{cases} \dfrac{x}{x_{brk}}, & x > x_{brk} \\ 1, & x \le x_{brk} \end{cases} \qquad (7)$$

Then, expression (1) is extended according to

$$L_{dB}^{(n)} = 20 \cdot \log\left[\frac{4 \cdot \pi \cdot d_n}{\lambda} D\left(\sum_{j=1}^{n} s_{j-1}\right)\right] \qquad (8)$$

where s_j is the physical distance along the path, see Fig. 3. This new expression (8) is reciprocal and can be generated recursively.

An example based on (8) is shown in Fig. 5, where the street orientation is according to the example in Fig. 1. The distance to the street crossing is 100 metres and the angles are 0, 10 and 90 degrees. The parameter q_{90}=0.5 and ν=1.5. The break point distance parameter was set to x_{brk} =300 metres.

The slope changes to 4 after the distance x_{brk} for the straight street and the bent street, θ_l =0 and 10 degrees, see Fig. 5. For the perpendicular street, θ_l =90 degrees, the slope is slightly higher. However, if the loss is described relative the distance to the corner, then the slope decreases to slightly less than 4, see Fig. 6.

The results according to the second suggested method are given in Fig. 7 and 8. The main difference is that (1) and (4) have been used instead of (8) and (2). Thus, no extra function is introduced for the latter method but the distance between the nodal points must be 1 metre. An additional difference is that, initially every nodal point, q_j, was set to 10^{-5} instead of 0, except for the nodal point which represents the corner, which was equal in the two cases.

The calculated losses with the two methods are very close and the maximum difference is about 2 dB. The main difference is that the loss has a smoother characteristic with the second method, Fig. 7 and 8, compared to the first method, Fig. 5 and 6.

The allocation method can be further extended, e.g. by giving different streets different constant q_j values. This could, for instance, be done as a function of the street width. The dependence of the antenna heights and ground height variation could also be considered, by making the q_j values a function of the distance between the ground and the "trace of the ray" between the antennas.

6 Further Model Extension

If necessary, expression (1) can be further extended by introducing another parameter, Q_j, for each nodal point, and applying it according to

$$L_{dB}^{(n)} = 20 \cdot \log\left(\frac{4 \cdot \pi \cdot d_n}{\lambda} \cdot \prod_{j=1}^{n-1} Q_j\right) \qquad (9)$$

It is obvious that this expression doesn't change the reciprocity properties, and that it is equal to (1) when Q_j=1 for all j. The benefit of introducing Q_j, is that it increases the possibilities to vary the model. It is of course also feasible to combine (9) with (8).

7 Ray Tracing Techniques

Ray tracing can be performed on different levels. A simplified method has been considered in this paper, with only one single ray propagating along each street. More elaborate methods can of course be applied, using several paths along each street, each one explicitly describing the multiple reflections between the buildings, the scattering from objects in the street crossings and diffraction around the corners.

8 Conclusion

It has been demonstrated that the suggested reciprocal and recursive method for street microcell path loss calculations:

- is very simple to apply
- is suitable for ray tracing techniques
- is very computer efficient
- is able to handle non perpendicular street crossings
- is able to handle bent streets
- generates acceptable path loss level
- can generate unique path loss variation for every individual street by allocating appropriate parameter values

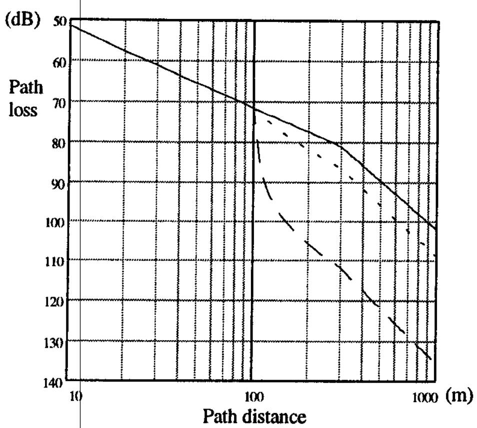

Figure 5 Loss as a function of the distance from the Tx. $\theta_l=0$, solid line, $\theta_l=10$, dotted line, and $\theta_l=90$ degrees, dashed line.

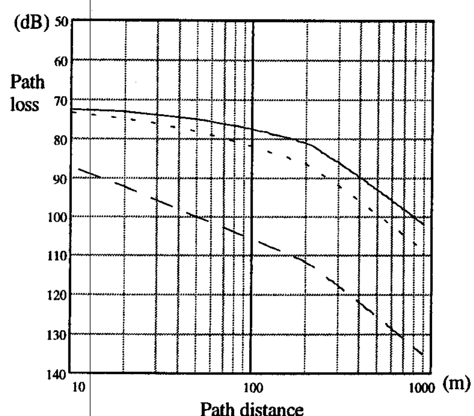

Figure 6 Loss as a function of the distance from the street corner. $\theta_l=0$, solid line, $\theta_l=10$, dotted line, and $\theta_l=90$ degrees, dashed line.

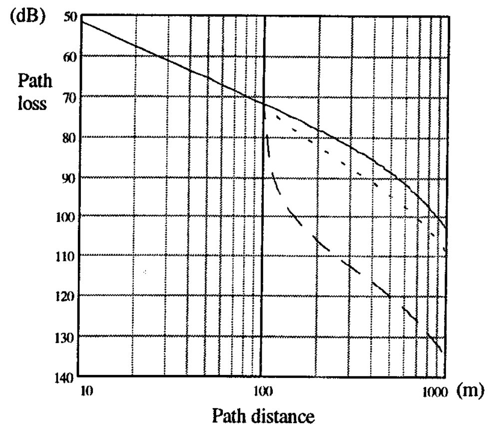

Figure 7 Loss as a function of the distance from the Tx. $\theta_l=0$, solid line, $\theta_l=10$, dotted line, and $\theta_l=90$ degrees, dashed line.

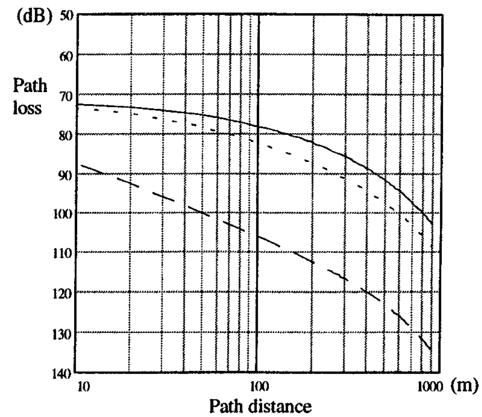

Figure 8 Loss as a function of the distance from the street corner. $\theta_l=0$, solid line, $\theta_l=10$, dotted line, and $\theta_l=90$ degrees, dashed line.

References

[1] J. Wiart, A. Marquis and M. Juy, "Analytical Microcell Path Loss Model at 2,2 GHz", *Proc. PIMRC'93, Yokohama*, pp.30-34, Sep. 1993

[2] J-F. Wagen and K. Rizk, "Simulation of Radio wave Propagation in Urban Microcellular Environments", *ICUP'93, Ottowa*, pp.595-599.

[3] J-E. Berg, R. Bownds and F. Lotse, "Path Loss and fading Models for Microcells at 900 MHz", *Proc. 42 nd Vehic. Tech. Conf., Denver*, pp. 666-671, May 1992.

[4] H. Xia, H. Bertoni, L. Maciel, A. Lindsay-Stewart and R. Rowe, "Radio Propagation Characteristics for Line-of-Sight Microcellular and Personal Communication", IEEE Trans. on A. P., Vol. 41, No 10,, pp. 1439-1447, Oct. 1993.