Proc. URSI Commison F Open Symposium on Radiowave Propagation and Remote Sensing, Garmisch-Partenkirchen, Germany, February 12-15, 2002.

ANALYSIS OF PROPAGATION LOSS IN URBAN MICROCELLS AT 1.9 GHZ AND 5.8 GHZ

T.C.W. Schenk[1,2], R.J.C. Bultitude[2], L.M. Augustin[2], R.H. van Poppel[2] and G. Brussaard[1]

[1] Eindhoven University of Technology (EUT), Department of Electrical Engineering, The Netherlands
[2] Communications Research Centre, Ottawa, Canada

PO Box 513,
5600 MB Eindhoven, The Netherlands,
Tel: +31641278532, Fax: +31402448375
E-mail: T.C.W.Schenk@student.tue.nl

Abstract

Continuous Wave (CW) measurements carried out in downtown Ottawa were used as the basis for comparisons between propagation loss at frequencies near 2 GHz and 6 GHz in urban microcellular environments. The difference (dB) was found to have a Gaussian distribution over urban microcellular coverage areas. To provide physical explanations for measured results, modelling was carried out at 2 GHz. During this process, low complexity models reported for other parts of the world were evaluated against the measurements, which were made in an urban area, which is typical of North America. Comparison of selected models with measurement data resulted in median root mean square (rms) modelling errors that ranged between 4 dB and 7 dB.

I. Introduction

The increasing demand for bandwidth in mobile radio systems is expected to force radio network operators to make more efficient use of scarce spectrum resources. It is well known that the use of microcells results in better traffic-handling capacity than conventional macrocells. Such systems have maximum coverage dimensions of only a few hundred metres and base station (BS) antennas that are well below the rooftops of the surrounding buildings, near street-lamp level.

Another possibility for extending network capacity is the allocation of higher frequency bands (e.g. around 3.6 GHz, 5.8 GHz and 10 GHz) for mobile communication. With respect to evaluation of the suitability of IMT2000-type systems, currently proposed for operation in a band near 2 GHz, in these higher bands, the propagation characteristics in one of these bands (i.e. 5.8 GHz) have been compared to those of frequencies around 2 GHz.

It was anticipated that models for propagation loss would provide physical explanations for results observed from measurements. A number of approaches to microcellular propagation loss prediction have been proposed in literature. Most of these use ray-tracing algorithms, which are very computationally intensive and need detailed descriptions of the operating environment. In contrast, a rapid prediction method using a combination of sub-models of low complexity initially proposed in [1], [2], and [3] will be discussed in this progress report. Sub-models are described for three different kinds of streets: the Line-Of-Sight (LOS) street, streets that are perpendicular to the LOS street and streets that are parallel to the LOS street, which show different propagation loss characteristics, as shown in [4].

Section 2 describes the measurement equipment and the measurements that were carried out. A comparison between propagation loss at frequencies near 2 GHz and 6 GHz is made in Section 3. In Section 4 models for propagation loss near 2 GHz are discussed and evaluated against results from analysis of the measured data.

II. Equipment and Measurements

CW measurements were carried out at both 1.9 GHz and 5.8 GHz in the downtown area of Ottawa, along all streets within a radius of about 1 kilometre centred on the transmitter. To simulate a microcellular base station (BS), the transmitter was mounted in a utility trailer that could be parked at the curbside. Equipment was powered using a gasoline generator, and the transmit antenna was supported by a steel mast, with adjustable height from the trailer's roof. An antenna height of six metres was used during measurements. A laboratory-built omnidirectional biconical antenna was employed. Reception was in a minivan with a laboratory-constructed quarter-wavelength monopole with drooping radials, mounted in the centre of its roof at a height of 1.7 metres above ground level. The in-situ radiation patterns of such antennas, when mounted on the measurement vehicle, have previously been found to be omnidirectional within ± 3 dB.

Received power was sampled at a rate of 2 ksamples/s at the output from a log-amplifier. During the measurements the distance from the beginning of each run was recorded 4 times per second to yield information on vehicle speed and location. For the modelling of the propagation loss on the LOS street measurement data from earlier measurements with the same measurement system in the downtown area of Toronto were also analysed, since there were only two BS sites in most recent Ottawa measurements, and therefore only two LOS streets. The Toronto measurements are further described in [5].

The influence of fast fading was removed from the recorded data, by estimating running averages for mobile receiver displacements of 40λ, based on [6], although it is recognised this strictly only applies to cases of Rayleigh fading.

III. Comparison of 2 GHz and 6 GHz results

Based on a comparison of the effective apertures of identical receive antenna types at the two frequencies, if the transmit powers are identical in free space, the difference in received power at the two frequencies would be $20 \cdot \log_{10}(\lambda_2 / \lambda_6)$, or 9.5 dB were λ_i, i = 2,6 represents the wavelength at operating frequencies of 2 and 6 GHz.

Comparison of the running averages at the two frequencies showed no obvious differences for streets with different orientations, nor was it possible to obtain meaningful and consistent results from any deterministic comparisons. It was observed, however, that, considering the fact that traffic conditions were almost certainly different when the sequential measurements were carried out at the two frequencies, the fading patterns in the running averages are remarkably similar. This indicates that significant power trends are greatly influenced by the fixed layout of buildings. Fig. 1 shows an example of measured results for both frequencies on a perpendicular street, 7 blocks from the BS.

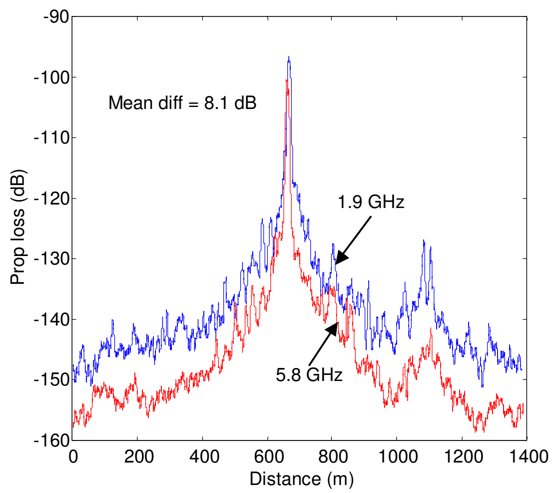

Figure 1: Comparison of measured propagation loss at frequencies near 2 GHz and 6 GHz on a street that is perpendicular to the LOS street.

To compare the propagation loss at the two frequencies the difference between received power, every metre along each street, was calculated. An experimentally-determined estimate of the cumulative probability distribution (ECDF) for these differences (in dB) was then found. For measurements centred on one BS the ECDF was found to be modelled well by a Gaussian distribution, having mean of 12 dB and a standard deviation of 4 dB. For the other setup, with a BS located one block to the West, on a perpendicular street, the appropriate model was also Gaussian, with standard deviation of about 4 dB, but it had a mean of 7 dB.

There is consistency of the standard deviations of the results from the two sites. However, the means of the best-fit models are considerably different from each other, and from the expected value of 9.5 dB. This difference can be explained by observations of the difference in the fading patterns of the running means as a function of distance along the street at the two frequencies. This pattern occurs over distances on the order of a few metres, and is referred to as shadow fading. It is a result of both multipath interference and the obstruction of waves by obstacles. The comparison, shown in Fig. 2, of the results from a simple two-ray model, comprising a direct path and a ground reflected one, in the absence of any obstruction shadowing, is a clear example of the difference in shadow fading at the two frequencies. The mean difference in the example of Fig. 2 is 13 dB and the standard deviation is 7 dB.

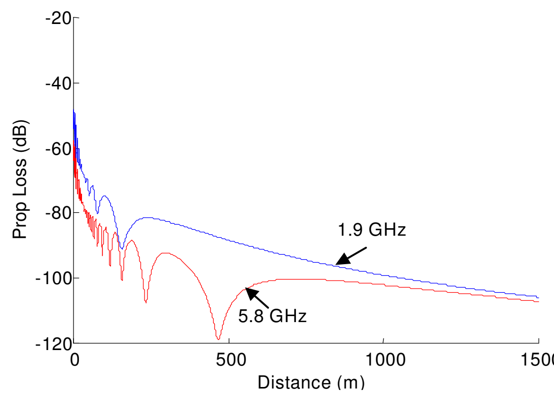

Figure 2: Comparison of two-ray model results for the same transmit/receive geometry at frequencies near 2 GHz and 6 GHz.

In the real world environments where the measurements were made, the multipath situations are considerably more complicated than those associated with the two-path model. It therefore seems reasonable to conclude that the 5 dB difference in the means for measurements centred on the two BSs is a result of the difference in multipath patterns associated with the local environments of the transmitters and the difference in street orientations. To further substantiate the conjectures, more comparisons are planned for different BS configurations.

Case	1	2	3	4	5	6	7	8	9
$h_0{}^r$ (m)	0.6	1	0.2	1.6	1.6	1.4	1	1	1.4
s^r	0.005	0	0.005	0	0.004	0.004	0.005	0.002	0.003
Rms error^r (dB)	6.8	2.8	4.2	3.4	3.1	3.2	2.6	4.7	3.6
$h_0{}^a$ (m)	1.2	1.4	0.2	1.6	1.6	1.2	1	1.6	1
s^a	0	0	0	0.001	0.004	0	0	0.003	0.004
Rms error^a (dB)	4.5	4.4	4.2	4.7	5.7	4.1	3.2	3.7	3.73

Table 1: Parameters of best fits using the modified two-ray model with corresponding rms errors wrt measured data. ^{r} = MS receding from the BS, ^{a} = MS approaching the BS.

IV. Propagation Loss Modelling

Results from models from the literature were evaluated against the measurements. The set of models that was chosen is described and compared with results from the 2 GHz measurements. The modelling is split into three parts: that for LOS streets, for perpendicular NLOS streets and for parallel NLOS streets.

a. A model for LOS streets

Line-of-sight measurements carried out along a road in a rural area showed that a two-ray model works well. This indicates that there are two dominant paths: a direct one and one via reflection from the road surface. In an urban microcell however, this model underestimates path-loss beyond a distance of about 100 metres, as can be seen in Fig. 3. In the case shown the two-ray model results in an rms error of 14.9 dB, which is not acceptable.

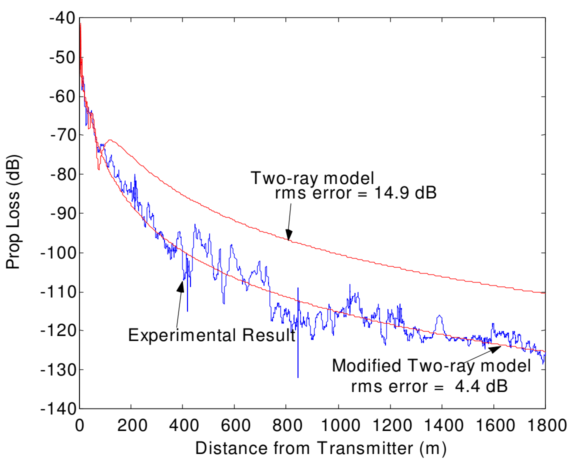

Figure 3: Experimental results from Toronto LOS street compared with predictions from a two-ray and a modified two-ray model (for h_0=1.4m and s=0).

It is believed that the underestimation occurs because the two-ray model does not take into account obstacles, which appear in an urban environment. A modified version described in [1] introduces a visibility factor s, due to shadowing by obstacles like trees and lampposts and a raised reflection surface h_0, due to obstacles on the road like vehicular traffic. The path-loss PL_{LOS} is expressed as [1]:

$$PL_{LOS}(r) = e^{-sr}\left(\frac{\lambda}{4\pi}\right)^2 \left|\frac{1}{r_t}e^{-jkr_t} + R\frac{1}{r_{rm}}e^{-jkr_{rm}}\right|^2 , \quad (1)$$

where r is the distance between base station and receiver, λ is the wavelength, k is the wave number, R is the reflection coefficient of the road surface [7], r_t is the distance between BS and mobile station (MS) and r_{rm} is the distance via reflection, which is expressed as:

$$r_{rm} = \sqrt{r^2 + \{(h_b - h_0) + (h_m - h_0)\}^2} , \quad (2)$$

with h_b the height of the base, and h_m the height of the mobile station, both with respect to the road surface.

This modified two-ray model was fit to the experimental results by varying the values of s and h_0. The parameter s was varied from 0 to 0.01 with steps of 0.001 and h was varied from 0 to 3.0 m, with steps of 0.2 m. For each measurement the combination of parameters yielding the smallest rms error were chosen. Fig. 3 shows the best fit for the modified two-ray model, with h_0 = 1.4 m and s = 0. The rms error is 4.4 dB. For the 18 street sections that were studied, model parameters for the best fits with the associated rms modelling errors are shown in Table 1. The value of h_0 was in the range of 0.2 to 1.6 metres and s varied from 0 to 0.005. The median of the rms errors of the best fits for this modified two-ray model is 3.9 dB.

Since there is currently no way of estimating values for s and h_0 from other information, such as street width or estimated traffic densities, a general model for Toronto and Ottawa was derived using the measurements. The combination of h_0 and s yielding the smallest median of the rms errors for the data pool was chosen for the general model. The parameters where varied in the same range and with the same steps as described above. This resulted in a general model with h_0 = 1.2 m and s = 0.001. The rms modelling errors of this generalised model are reported in Table 2. The median rms error is 5.7 dB. The parameters of the general model are different of those reported in [1], which reports a speculation that the parameters h_0 and s vary from city to city.

Case	rms error ^{r} (dB)	rms error ^{a} (dB)
1	7.5	5.5
2	3.1	5.1
3	6.3	13.8
4	4.3	8.3
5	11.1	5.8
6	5.6	5.8
7	3.6	5.5
8	4.8	5.4
9	8.5	7.8

Table 2: Rms propagation loss prediction errors (dB) wrt measured data obtained using the modified two-ray model with h_0 = 1.2m and s = 0.001.

b. A model for perpendicular NLOS streets

From measurements it was observed that on streets that are perpendicular to the LOS street, propagation loss has a general trend of increasing with distance from the intersection with the LOS street. The modelling of power loss along perpendicular streets discussed here relies on a virtual source technique that was initially proposed in [2]. Virtual sources at each intersection along the LOS street are located such that they have line-of-sight with the mobile station on the perpendicular streets. Propagation loss is expressed by [2]:

$$PL_{perp}(r) = \alpha \cdot \left(\frac{\lambda}{4\pi r_s}\right)^2 \cdot \frac{2xW_s}{4\pi r^2}, \qquad (3)$$

where r_s denotes the distance between the virtual source and the BS, x equals the distance between the sidewall and the BS, W_s denotes the width of the perpendicular street and r is the distance between the virtual source and the MS. The factor α is an empirical parameter to account for variations in propagation characteristics along different streets.

Herein, modelling is only considered for distances up to 300 metres from the LOS street, because it was found difficult to reach any consistency in the results for greater distances. Therefore the breakpoint as proposed in [2], was not taken into account. It is considered that a model that is valid over 300 metres would be useful when considering desired received signal powers in microcellular environments. However, for application in interference studies, modifications and extensions are needed.

It was attempted to find a typical value for α. The distance between the BS and the sidewall x was taken as 2 m, and the width of the perpendicular street was taken to be 20 m for modelling purposes, which is about the average street width in Ottawa. In Fig. 4 the result of applying the model with $\alpha = 0.2$ is shown with the running mean of measured data for a perpendicular street in Ottawa along a street section South of the LOS street.

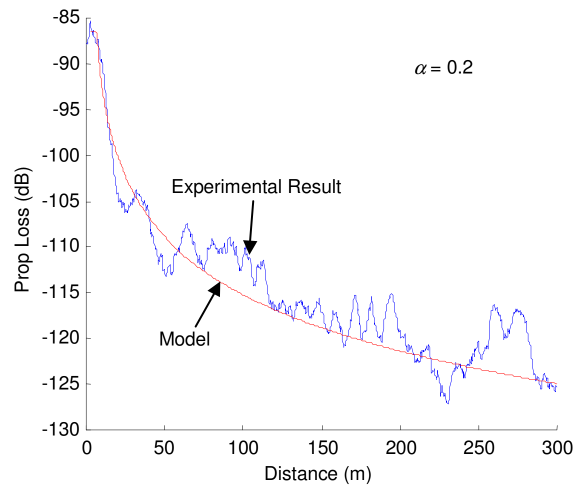

Figure 4: Comparison of the running mean of measured data from a perpendicular NLOS street with the result of applying the recommended model with α = 0.2.

The values of α for the best fits of the model for the different perpendicular streets are shown in Table 3. They range from 0.05 to 0.8, with no apparent dependence upon distance of the NLOS street from the base station.

Street	Distance from BS (m)	α (South)	α (North)
1	594	0.05	0.2
2	410	0.07	0.07
3	239	0.2	0.2
4	66	0.2	0.05
5	108	0.3	0.03
6	298	0.1	0.8
7	430	0.03	0.2
8	579	0.1	-

Table 3: Values for α for different perpendicular streets.

For globalisation of this model, the median value of α = 0.2 was chosen. This resulted in rms errors as reported in Table 4 that range from 2.6 dB to 9.2 dB, which have a median of 4.1 dB and a standard deviation of 1.9 dB.

The second term in (3) represents the free space model, which is used to calculate the power radiated from the virtual source. It is acknowledged that this is in contradiction with what is proposed in Section IV.a. It is considered that this free space term should be replaced with the modified two-ray model, since this better models the power in the LOS street. In this case the height of the virtual source can not simply be assumed to be the height of the transmitter. Further investigation concerning this was, however, left as a topic for further study.

Street	Rms error (South)	Rms error (North)
1	7.4	5.4
2	9.2	3.8
3	3.7	2.6
4	6.7	6.7
5	3.6	2.4
6	4.6	4.7
7	3.3	3.4
8	4.1	-

Table 4: Rms errors (dB) wrt measured data for virtual source model with $\alpha = 0.2$.

c. A model for parallel NLOS streets

It was observed that on streets that are parallel to the LOS street, the average received power increases in an arc-like fashion as the MS moves along the street from its farthest distance from the BS to a position adjacent to it. The radius of the curvature decreases as the distance of the parallel street to the LOS street increases. Above the local average there are power peaks at every intersection with the perpendicular NLOS streets and one adjacent to the location of the BS.

The model recommended here reflects these characteristics and is based on the model for the perpendicular NLOS streets. It places a virtual source at the intersection between the parallel and the perpendicular street and was initially proposed in [3]. Some modifications were made to this model that are novel contributions of this work. Multiple sources are added, one on each intersection, and under an assumption that spatial variations within any small local area of components of power received from them are mutually uncorrelated, their contributions are summed at the receiver. A term that represents power that arrives directly, through either rooftop diffractions or building penetrations, from the BS is also included. This addition was initiated from [8] and as a result of multipath angle of arrival estimations carried out on the measurements, which showed a persistent contribution on parallel NLOS streets that arrives from the direction of the BS. A final modification was made, which adds a virtual source on the parallel street, adjacent to the BS.

Propagation loss on parallel NLOS streets is then expressed as:

$$PL_{par} = \left[\sum_{n=0}^{N} \alpha_n \left(\frac{\lambda}{4\pi r_{sn}}\right)^2 \cdot \frac{2xW_{sn}}{4\pi r_n^2} \cdot \frac{WW_{sn}}{4\pi R_{sn}^2}\right] + \left[\frac{1}{\beta R_{bm}}\left(\frac{\lambda}{4\pi R_{bm}}\right)^2\right], \qquad (4)$$

where the notation is the same as in (3) except that a subscript n has been added in some cases to identify a parameter as being associated with the n-th perpendicular NLOS street, $n = 0$ identifies the virtual source adjacent to the BS, and R_{sn} is the distance along the parallel street to the mobile terminal from the virtual source at its intersection with the n-th perpendicular NLOS street. The parameter R_{bm} is the direct distance from the base station to the mobile, β is an empirically derived constant to account for the attenuation along the usually obstructed path between the base station and the mobile, and W is the width of the parallel street.

Applying (4) with $\alpha_n = 1$ for all parallel streets and tuning β for the lowest rms error with respect to the running averages from the measurement data, resulted in values of β that ranged from 1 to 24 and rms errors ranging from 3 dB to 5 dB. There was also an indication that β increased with the perpendicular distance between the parallel and the LOS street, symmetrically in both directions from the LOS street. Fig. 5 gives an example of results from applying the model to predict running averages on a parallel NLOS street in Ottawa. Optimisation of the results for both the parameters α_n and β has not yet been attempted, nor has a global model been derived.

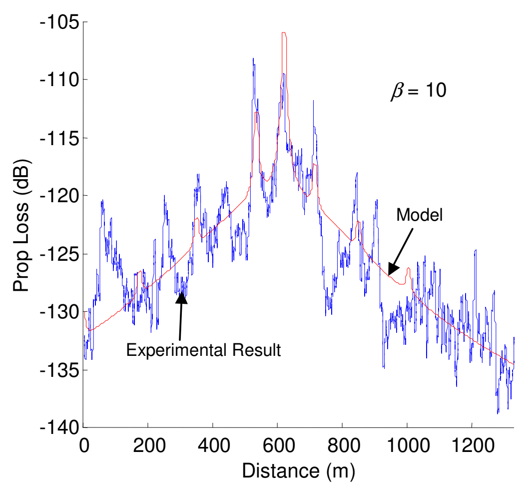

Figure 5: Comparison of the running mean of measured data from a parallel NLOS street with the results of applying the recommended model with $\beta = 10$.

V. Conclusions and further work

From work reported herein it is concluded that the difference between propagation loss at 2 GHz and 6 GHz can be modelled as having a Gaussian distribution, with a standard deviation of about 4 dB and a mean that is approximately equal to the difference in effective areas of the antennas at the two frequencies. It is also concluded that the mean difference varies for different base station configurations, because of slow fading related to the geometry of the operating environment. To further substantiate these conclusions, more comparisons are needed for different BS configurations.

Although more work is required to complete the development of the models for propagation loss, current versions show very promising results. The modified two-ray model for LOS streets gives good results. The visibility and raised reflection factors vary from street to street, but for Toronto and Ottawa, a single generalisation of the values, i.e. of h_0 = 1.2m and s = 0.001, resulted in rms errors with respect to measurements that ranged between 3.1 dB and 13.8 dB, with a median of 5.7 dB.

The virtual source model for perpendicular NLOS streets also yields reasonable results. It is considered, however, that it should be altered by using the modified two-ray model to calculate the power of the virtual source and extended for applicability for distances greater than 300 metres along perpendicular streets. A general version of this model for perpendicular Ottawa streets, with $\alpha = 0.2$, gave an rms error with respect to measurements that ranged between 2.6 dB and 9.8 dB, and had a median of 4.1 dB.

It is concluded that several improvements can be made to the model proposed in [3] for parallel NLOS streets. These include: adding multiple virtual sources at intersections with all perpendicular streets and one adjacent to the BS in the LOS street. A term representing power arriving directly from the BS should also be included.

Initial work on the model for parallel NLOS streets gave results with rms errors with respect to experimental results that ranged between 3.4 dB and 5.0 dB, with a median of 4.2 dB. However, it is concluded that even lower rms errors are possible with simultaneous optimisation of α and β.

Finally, it is concluded that accuracies that are comparable to those achievable through ray tracing can be obtained using the proposed model-set, provided the model parameters can be tuned to sampled data. Methods to achieve this tuning from map observations, and hence obviate even tuning measurements are under consideration.

Acknowledgements

The authors would like to acknowledge contributions that were made to this work by upgrading of the measurement system, and in the conduct of the measurements, by Tyler Smith and Raymond Bérubé. Nicole Op den Kamp and Nikhil Adnani are also deserving of recognition for their participation in the measurements.

References

[1] Y. Oda, K. Tsunekawa and M. Hata, "Advanced LOS path-loss model in microcellular mobile communications", IEEE Trans. Vehicular Techn., vol. 49, (6), Nov. 2000, pp. 2121 – 2125.

[2] H.M. El-Sallabi, "Fast path loss prediction by using virtual source technique for urban microcell", IEEE VTC 2000-Spring Tokyo, pp. 2183 – 2187.

[3] Wei Zhang and N. Moayeri, "Explicit expressions for the prediction of micro-cellular mobile radio propagation in urban street grid environments", IEEE Antennas and Propagation Society International Symposium 2000, pp. 1118 – 1121.

[4] J.H. Whitteker, "Measurement of path loss at 910 MHz for proposed microcell urban mobile systems", IEEE Trans. Vehicular Techn., vol. 37, (3), Aug. 1988, pp. 125 – 129.

[5] R.J.C. Bultitude and D.A. Hughes, "Propagation loss at 1.8 GHz on microcellular mobile radio channels", Proceedings PIMRC'96, 1996, (3), pp. 786 – 790.

[6] W.C.Y. Lee and Y.S. Yeh, "On the estimation of the second order statistics of log-normal fading in mobile radio environment", IEEE Trans. Comm., vol. 22, June 1974, pp. 869 – 873.

[7] H.H. Xia, H.L. Bertoni, L.R. Maciel, A. Lindsay-Stewart and R. Rowe, "Radio propagation characteristics for line-of-sight microcellular and personal communications", IEEE Trans. Anten. & Prop, vol. 41, (10), Oct. 1993, pp. 1439 – 1447.

[8] Y.L.C. de Jong, M.H.A.J. Herben, J.-F. Wagen and A. Mawira, "Transmission of UHF radiowaves through buildings in urban microcell environments", Electronics Letters , vol. 35, (9) , 29 Apr. 1999, pp. 743 –745.