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Propagation models for high sites in urban areas

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Abstract. Analyses of results from commonly used propagation models applied to UMTS Ultra High Sites in urban environments are presented. Differences between predicted and measured values for a site in Nuernberg are calculated as a function of the distance between base station and mobile station and as a function of the angle of incidence. An assessment of the validity range of the different propagation models is done. Furthermore, an analysis of the accuracy of the classification of building data is presented.

1 Introduction

An ultra high site (UHS) is a base station (BS) location with an antenna mounted at very high spots like TV towers or chimneys. Typical antenna heights are more than 100 m. Therefore, the probability of line of sight (LOS) increases because shadowing effects become less frequent as obstacles of more than 100 m in height are rare. As a consequence, the communication range is 2-4 km in urban areas and 6 km in suburban areas. In order to solve the capacity problem, an unusual high number of sectors with relatively narrow beams is used. So it is possible to cover an area with one UHS for which normally eight conventional sites are necessary (Boensch, 2004), as depicted in Fig. 1.

The German network operator E-Plus uses this principle for providing coverage in the initial roll-out of its UMTS network which is cheaper and also faster. Until the end of 2004, E-Plus built 200 ultra high sites instead of 1500 conventional sites. A cost saving of about 60 mill Euros is expected until the end of 2005 (Boensch, 2004). Commonly used propagation models applied to planning of cellular networks in urban areas have been developed for typical antenna heights of up to some ten meters. Therefore, the antenna height of UHS is out of the original validity range of these models. Consequently, the impact of elevated antennas on the prediction accuracy has to be analysed. Furthermore, input data, especially those which characterise buildings, have an impact on the prediction accuracy which is also analysed.

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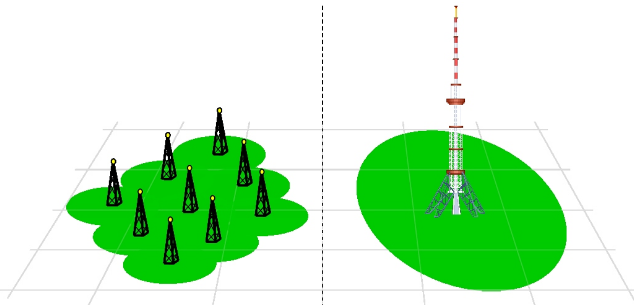

Fig. 1. Comparison of network expansions with and without using UHS.

In Sect. 2 the considered propagation models are described followed by their analysis with measurement data in Sect. 3. In Sect. 4 the characterisation of building data is introduced followed by the analysis of results in Sect. 5.

2 Propagation models

Since coverage of the first phase of the UMTS roll-out concentrates on urban areas, the analysis presented in this paper is limited to urban macro cells. A typical situation is given in Fig. 2.

The important parameters for such a situation are the BS antenna height h_b, the mobile station (MS) antenna height h_m, the mean building height h_r, the street width w, the building separation b, the length of the propagation path over the buildings l, the distance between the BS and the buildings r, the distance between BS and MS d, and the angle of

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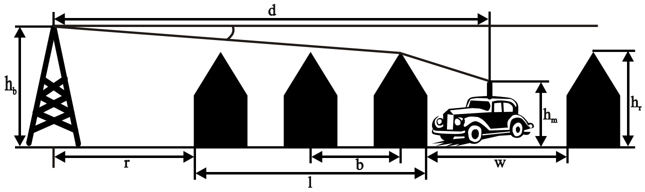

Fig. 2. Typical situation in urban macro cells.

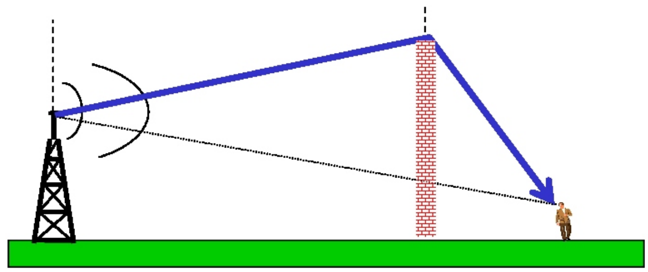

Fig. 3. Free space propagation with one diffraction edge.

incidence from the BS to the first diffraction edge α. An important parameter to determine the applicability to situations with grazing incidence is the settled field distance d_s (Eggers, 1991) defined as

$$d_s = \frac{\lambda d^2}{(h_{\mathrm{eff}} - h_r)^2} \quad (1)$$

with the wave length λ. d_s has a strong relation to α. The validity range of the models is further extended to inhomogenious areas by introducing the effective BS antenna height h_{eff}. A number of propagation models covering such situations are reported in the literature (COST231, 1991; Kuerner et al., 1996; Maciel et al., 1993; Saunders and Bonar, 1994).

The propagation models analysed in this paper can be classified into simple propagation models and urban ones. Simple propagation models are the free space model and the COST231-Okumura-Hata model. The free space model considers a free space path loss component and a single knife-edge diffraction loss taking into account the diffraction at the last building, see Fig. 3. The COST231-Okumura-Hata model calculates the path loss by attenuation coefficients. Explicit diffraction losses are not included. Additional losses in urban areas are considered with a constant correction factor of 19.6 dB (Rakoczi et al., 2003). Although these two models are better suited for open areas, they can also be used for UHS because of the higher LOS probability.

The COST231-Walfish-Ikegami model, the Flatedge model, and the Maciel-Xia-Bertoni model are better suited for urban areas. The COST231-Walfish-Ikegami model (COST231, 1991) distinguishes LOS and NLOS (non line of sight). It is valid for effective BS antenna heights up to 70 m and for large values of α, i.e. for $l > d_s$. For grazing incidence this model is poor (Kuerner et al., 1996). In this case the Flatedge model (Saunders and Bonar, 1994) provides reasonable results as long as the distance between the BS and the first building is much larger than the propagation path over the buildings, i.e. as long as $r \gg l$. This model can be applied to antenna heights above 70 m. The Maciel-Xia-Bertoni model (Maciel et al., 1993) has been developed for all "typical" antenna heights without further restrictions.

In Kuerner et al. (1996) it is shown that a combination of the Walfish-Ikegami, the Flatedge, and the Maciel-Xia-Bertoni model is superior to each of the single models. Therefore, in this hybrid model, the Walfish-Ikegami model is chosen as long as $h_{\mathrm{eff}} < 70$ m and $l > d_s$, whereas the Flatedge model is applied if $r \gg l$, $h_{\mathrm{eff}} \geq 70$ m and $l \leq d_s$. The Maciel-Xia-Bertoni model closes the gap in the validity range of both models.

If this hybrid model is applied to UHS, the Walfish-Ikegami model is never chosen, since antenna heights above 100 m lead to effective antenna heights larger than 100 m, too. As long as the UHS is located in urban areas, the Flatedge model is never used, since no profile exists that fulfils the criteria $r \gg l$. As a consequence, only the Maciel-Xia-Bertoni model is selected within the hybrid model in case of a UHS scenario.

3 Analysis of the propagation models

Measurement data were provided by E-Plus for a UHS location in Nuernberg with an antenna height of 273 m. The site has nine antennas, each of them covering sectors of 40° width. Measurement data are only considered if the MS is located in urban environment and in the serving sector in order to avoid inaccuracies due to the antenna diagram. Comparison between the measured values and the predicted ones is done by calculating the mean error between prediction and measurement as a function of the distance between BS and MS and as a function of the angle of incidence α, respectively. The results are shown in Figs. 4 and 5.

Due to the selection rules of the hybrid model explained in section 2, the results of the Maciel-Xia-Bertoni model are identical to those of the hybrid model so that both curves overlap. These two models only show reasonable results if $d > 2$ km and $\alpha < 10°$. Especially for large values of α, the mean error becomes very large. In these ranges, the Walfish-Ikegami model shows a good correlation between prediction and measurement. The Flatedge model and the COST231-Okumura-Hata model show good results for large distances, but the prediction with the COST231-Okumura-Hata model becomes too optimistic for larger α. In contrast to this, the free space model just taking into account a single knife edge has a high mean error for large distances because of underestimating the losses from multiple screen diffraction phenomena.

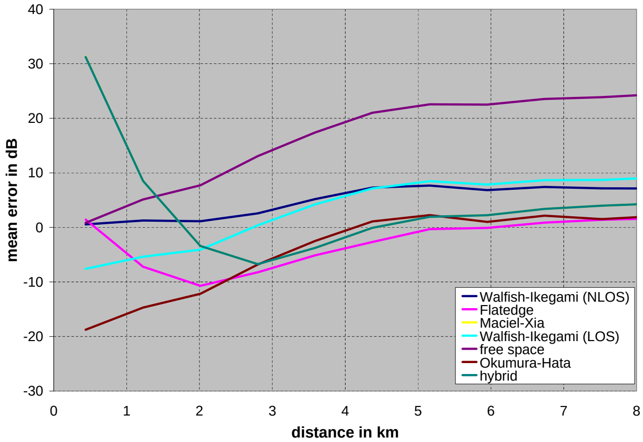

Fig. 4. Mean error between prediction and measurement as a function of the distance d between BS and MS.

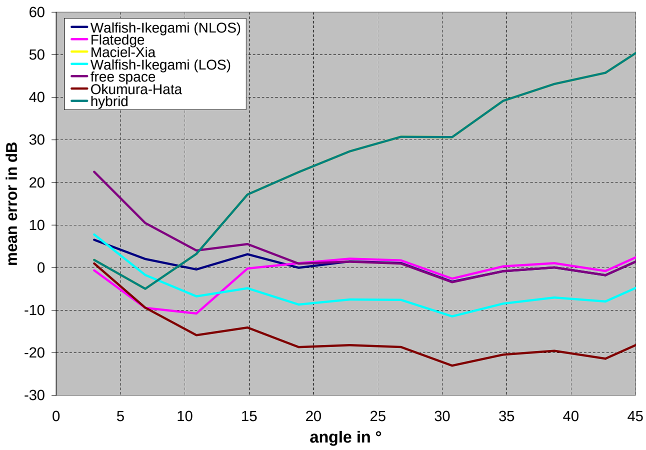

Fig. 5. Mean error between prediction and measurement as a function of the angle of incidence α.

The analysis confirms the superior behaviour of a hybrid model. For small distances the Walfish-Ikegami model shows very good results, but for larger distances great deviations occur. On the other hand, looking at large distances, the Maciel-Xia-Bertoni and the COST231-Okumura-Hata model perform very well. Therefore, the selection rules of the original hybrid model are extended to consider the behaviour in a UHS scenario. The Walfish-Ikegami model is chosen for UHS if $\alpha > 8°$. The Flatedge model is selected in a UHS scenario for $d > 400$ m, and the Maciel-Xia-Bertoni model closes the gap between the extended validity ranges. The mean errors of this extended hybrid model as a function of the distance d between BS and MS and of the angle of incidence α can be seen in Figs. 6 and 7 in comparison to the original one.

The great deviation of the original model for small distances and great angles can be avoided with the new hybrid

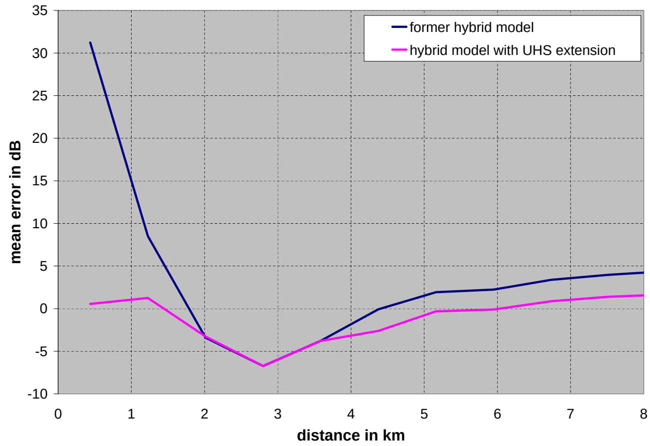

Fig. 6. Mean error between prediction and measurement for the old and new hybrid model as a function of the distance d between BS and MS.

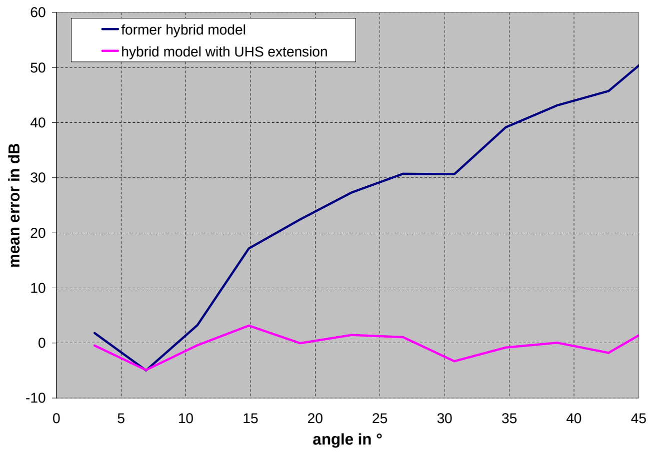

Fig. 7. Mean error between prediction and measurement for the old and new hybrid model as a function of the angle of incidence α.

models. For the whole range of the distance and the angle, the mean error is about 0 dB. Altogether, the mean error and the standard deviation of the new model are improved by about 1 dB, see Table 1.

Table 1. Mean error and standard deviation between prediction and measurement for the old and new rule set of the hybrid model

	former model	with UHS extension
mean error	-1.6	1.0
standard deviation	9.7	8.6

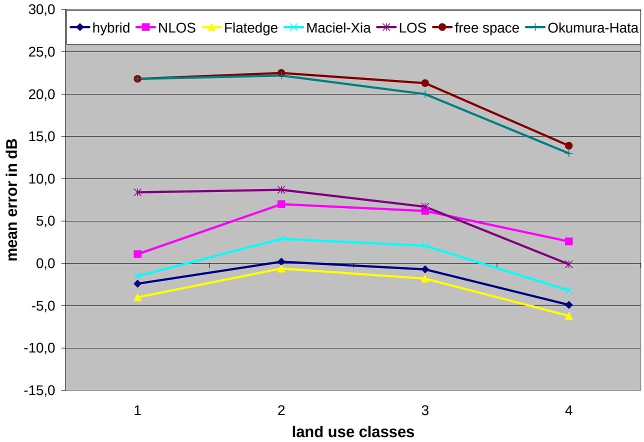

Fig. 8. Mean error for the prediction and analysis with the land use classes.

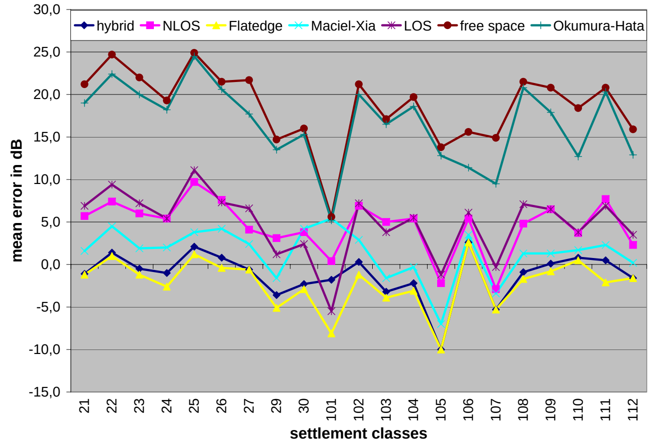

Fig. 9. Mean error for the prediction with the land use classes and analysis with the settlement classes.

4 Characterisation of buildings

The propagation models need input data of the calculation area to be able to calculate the path loss. Part of these input data is usually information about the terrain height and land use. Hence, it is possible to distinguish between open, forested, and urban areas. With this classification in so-called land use classes, the propagation model suiting the corresponding environment best can be chosen. The accuracy of the classification of land use classes has a strong impact on the accuracy of the prediction. In the following, this impact is analysed for urban classes.

In the hybrid model, four urban land use classes have been used by E-Plus: dense urban, urban, suburban, and industry (classes 1–4). In order to improve classification of urban areas, E-Plus has now introduced 21 settlement classes (E-Plus, 2004). These classes can be divided into nine classes to characterise the structure of buildings like one-family houses or high-rise buildings (classes 21–30) and 12 classes to specify institutions like schools or airports (classes 101–112). Each of these classes has its own characteristic parameters to describe the street width, the building height, and the building separation of the specified area. Therefore, the 21 settlement classes can give a more accurate picture of the building structure than the four land use classes.

In the following, the analysis of the influence of the more accurate classification on the prediction accuracy is presented.

5 Analysis of the land use classes

The measurement data of Nuernberg are used to calculate the mean error between measurement and prediction for each of the land use classes. Four cases are considered to analyse the impact of the accuracy: prediction on basis of the land use classes and analysis with the land use classes, prediction on basis of the land use classes and analysis with the settlement classes, prediction on basis of the settlement classes and analysis with the land use classes, and finally, prediction on basis of the settlement classes and analysis with the settlement classes. The results for the prediction on basis of the land use classes are shown in Figs. 8 and 9.

Table 2. Mean error and standard deviation between prediction and measurement for the prediction (pred.) and analysis with the land use classes and settlement classes

		analysis			
		land use classes		settlement classes	
pred.	land use classes	-1.2	8.7	-0.6	8.5
	settlement classes	-2.7	9.4	-3.5	9.0

The analysis with the land use classes shows good results for the urban propagation models. Only the simple models show poor results. The prediction results of these two models are about 15-20 dB too optimistic. This is approximately the value of the constant correction factor in the COST231-Okumura-Hata model. Thus, this correction factor leads to an underestimation of the pathloss. The free space model underestimates the pathloss because it only takes into account a single knife edge diffraction loss. With the settlement classes the analysis is more detailed. Figure 9 shows that some of the classes representing special institutions, namely the classes 101, 105 and 107, cause problems to most of the propagation models whereas the other classes show reasonable results. The more accurate analysis also reflects in the standard deviation, as shown in Table 2.

Both standard deviations, for the prediction on basis of the land use classes as well as for the prediction on basis of settlement classes, are smaller if the results are analysed with the more accurate settlement classes than if the results are analysed with the land use classes because the deviations can be reduced with the more accurate classification.

6 Conclusions

In this paper, propagation models for urban areas using UHS have been analysed with measurement data from an operating UMTS network in Nuernberg. The focus has been set on the difference between prediction and measurement data as a function of the distance and the angle of incidence. It was shown that the Maciel-Xia-Bertoni model is not valid for typical antenna heights of UHS as long as the angle of incidence α is larger than 8°. However, the COST231-Walfish-Ikegami model has shown excellent performance in this range as long as the distance d between BS and MS is smaller than 2 km. Therefore, an alternative rule set for the hybrid model has been presented to overcome the disadvantages of the former model. Furthermore, the importance of the accuracy of input data, especially of the characterisation of the buildings, was analysed. It was shown that the accuracy of the classification of buildings has a strong impact on the accuracy of the analysis. With a more accurate classification, the parameters describing a specified area could be determined in more detail so that the deviations could be reduced.

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