Impact of Building Database Accuracy on Predictions with Wave Propagation Models in Urban Scenarios

Alexander Aschrafi, Philipp Wertz, Michael Layh, F.M. Landstorfer

Institute of Radio Frequency Technology
University of Stuttgart
Pfaffenwaldring 47, 70569 Stuttgart, Germany
www.ihf.uni-stuttgart.de

Gerd Wölfle, René Wahl

AWE Communications GmbH
Otto-Lilienthal-Str. 36, 71034 Boeblingen, Germany
www.awe-communications.com

***Abstract*—The accuracy of predictions with wave propagation models depends significantly on the quality of the building databases, as they show discrepancies when compared to reality. This is due to the inaccuracies of the photometric methods used to create these databases, but also to the fact that new buildings are raised or old buildings are pulled down. However, propagation models should feature a certain robustness against these inaccuracies. In this paper, the sensitivity of different propagation models for urban scenarios with respect to building database inaccuracies is analyzed. The main focus is the comparison of the Dominant Path model with a Ray Tracing model, but the results are also put in relation to the empirical COST 231 Walfisch-Ikegami model. Furthermore, the possibilities of an automatic database simplification to reduce calculation times are investigated, and it is shown that Ray Tracing computation times can be reduced up to 50% with only slight decreases in the accuracy by applying suitable simplification algorithms. For the evaluation of the influence on the accuracy also path loss measurements in different scenarios were used.**

***Keywords*—Wave Propagation, Ray Tracing, Dominant Path Model, Building Database Accuracy, Building Database Simplification**

I. INTRODUCTION

TODAY, a number of different wave propagation models for urban scenarios is available for mobile network planning [1]-[5]. All these models rely on vector building databases. Two major problems arise here: On one hand, the license cost of building databases correlates with their precision, i.e. highly detailed databases are in many cases not economically reasonable, especially for network planning purposes where large scenarios have to be handled. On the other hand, every urban scenario undergoes a constant change in terms of reconstruction and demolition of buildings, not to mention inherent errors resulting from the photometric generation of the databases.

Research work to gain knowledge about the effects of database inaccuracies has already been done [8],[9]. However, in these studies, no comparison was made between different propagation models, as only standard Ray Tracing models were researched. This paper has a different objective, as it compares the effects of database inaccuracies and simplifications on different propagation models, using existing results of measurement campaigns from several scenarios. This makes it on one hand possible to draw a general comparison between empirical, semi-empirical and deterministic wave propagation models. On the other hand, it allows the evaluation of the effects due to automated database simplification in terms of computation time and prediction accuracy.

In [1], a wave propagation model based on the determination of dominant paths was presented that, apart from lower computation times at similar accuracy, is expected to offer a higher independence from inaccuracies in the database compared to Ray Tracing models [2]-[4]. This Urban Dominant Path Model (UDP) is based on the fact that not all potential rays between transmitter and receiver contribute similar energy to the total received power. In fact, only a few propagation paths are dominant in terms of power contribution. By determining these paths, the computation time can be reduced significantly with only slightly decreasing the accuracy.

Due do its approach, the Dominant Path model does not rely on details of the building database, which suggests a higher robustness against inaccuracies in the database. In this paper, the results of a direct comparison concerning the robustness of the two models will be presented.

Furthermore, a tool for complexity reduction of urban databases integrated in [6] is analyzed. The paper also shows in how far this tool allows the reduction of the computation times of different propagation models under consideration of the resulting error from these simplifications.

II. PROCEDURE

A. Comparisons without measurements

In a first step, scenarios where no measurements were available are investigated.

After manipulations (either simplification or falsification of the database), the resulting predictions is subtracted from the prediction gained with the original database. The difference map (see figure 1) is analyzed in terms of the mean difference and the standard deviation.

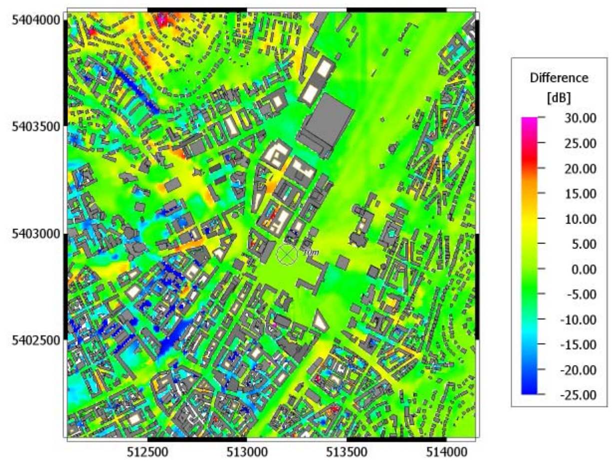

Figure 1: Difference chart in scenario Stuttgart

B. Comparisons with measurements

In a second step, comparisons with measurement campaigns are made in multiple scenarios. A typical example is shown in figure 2 [7].

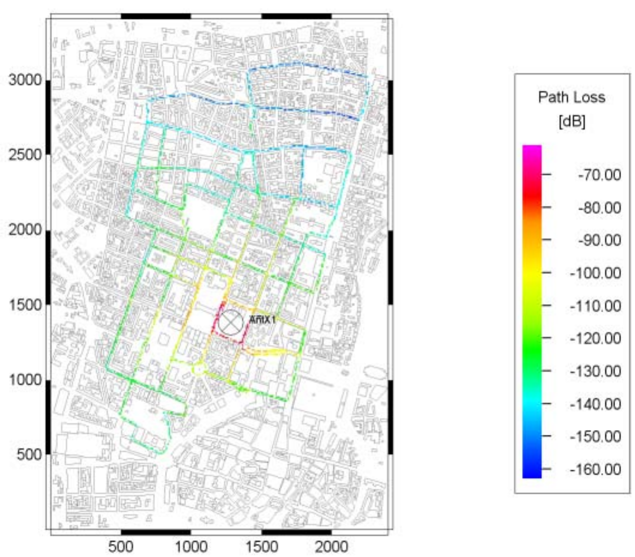

Figure 2: Example for a measurement campaign in Munich

For the evaluation, the values of the measurement pixels are subtracted both from the predictions made with the original database and the changed database, and the mean error and the standard deviation are computed for both cases.

III. INFLUENCE OF THE TRANSMITTER HEIGHT

First, a comparison between the Urban Dominant Path model (UDP), the Intelligent Ray Tracing model (IRT) and the COST 231 Walfisch-Ikegami model [7] was performed under the following conditions.

In a detailed database of the city of Stuttgart, a virtual transmitter is placed on different heights: 10m for a typical below rooftop level situation, 25m for a location on rooftop level, and 40m for a higher site. The chosen transmitting frequency is 948 MHz using an omnidirectional antenna at 10W transmitting power.

The database now is automatically simplified in two steps according to table 1. The automatic detection of courtyards is additionally included in both simplification levels. An example for a level 2 simplification is shown in figure 3.

Simplification Scheme			
	Level 0 (orig.)	Level 1 (typ.)	Level 2 (strong)
erase all buildings smaller than	-	1m	1m
erase redundant corners	-	yes	yes
corner reduction degree	-	10	40
combination of adjacent buildings, max. height difference	-	5%	25%
Elements in database	19665	18901	17170
Average corners per building	6.22	5.14	4.12

Table 1: Simplification scheme

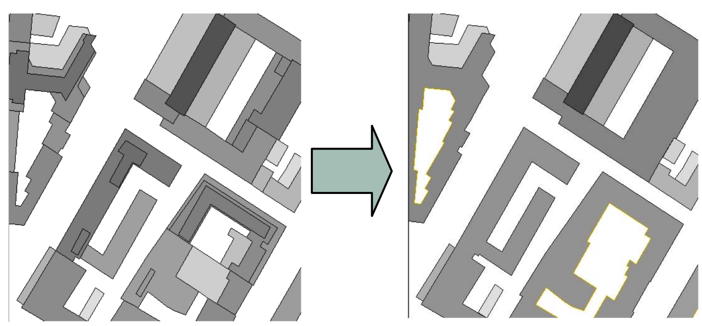

Figure 3: Example for a level 2 simplification

For all simplification levels, predictions are made using the Intelligent Ray Tracing (IRT) model [4], [5] in rigorous 3D mode and the Dominant Path model [1]. The pixel resolution is set to 10 meters at a prediction height of 1.50 meters. The field strength is predicted in a rectangular area inside the city.

The averaged difference (AD) and the standard deviation (SD) of the respective difference maps can be viewed in table 2**.** The charts in figure 4 and 5 illustrate these numerical results.

Averaged Differences and Standard Deviations [dB]												
TX Height	*IRT*				*UDP*				*COST 231*			
	Level 1		*Level 2*		*Level 1*		*Level 2*		*Level 1*		*Level 2*	
	AD	*SD*	*AD*	*SD*	*AD*	*SD*	*AD*	*SD*	*AD*	*SD*	*AD*	*SD*
10 m	1.4	3.5	2.2	7	-0.3	1.7	-0.8	4.5	-0.4	1.1	-1.4	2.6
25 m	0.7	2.2	1.1	3.7	0	1.2	0	3.3	-0.6	1.5	-2.1	3.7
40 m	0.4	1.8	1	3	0	0.8	0	2.3	-0.3	0.8	-1.1	2

Table 2: Averaged differences and standard deviations of the subtracted predictions at different transmitter heights

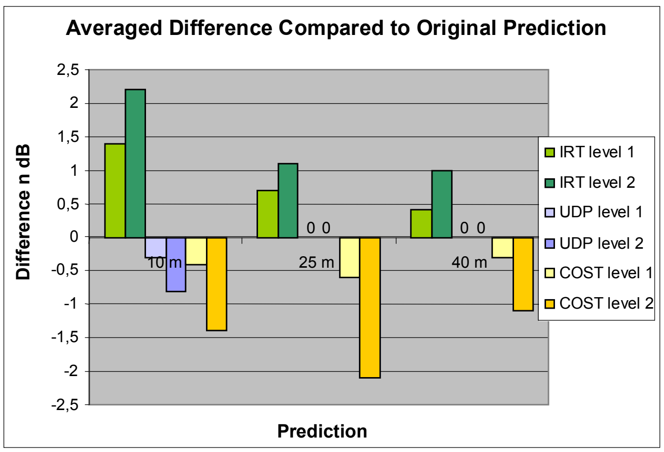

Figure 4: Averaged difference compared to the original prediction

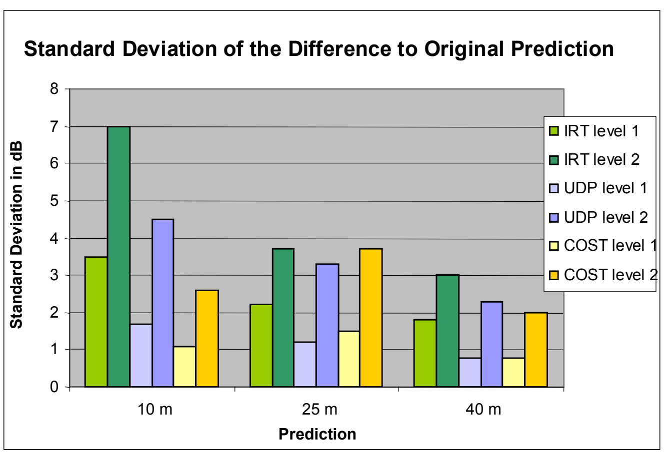

Figure 5: Standard deviation of the difference to the original prediction

From these charts, two conclusions can be drawn:

On one hand, it is clearly visible that for the two deterministic models the influence of the database changes is reduced when raising the transmitter position. For the empirical COST 231 model, no such dependency is noticeable.

Secondly, both in terms of the mean difference and the standard deviation, the Dominant Path model turns out to be more robust than the Ray Tracing model. Especially when considering the mean difference, there are no changes in the results of the Dominant Path model for transmitter heights of 25m and 40m, whereas with the Ray Tracing model, especially for a level 2 simplification, significant differences occur.

IV. Manipulations in Building Databases

In the following, to simulate cartographic inaccuracies and typical changes in urban areas, manipulations in databases are done. For this, seven scenarios according to table 3 are used:

Scenario	Frequency (MHz)	Antenna Characteristic	TX Power (W)	Antenna Height (m)
Munich	947	omnidirectional	10	13
Stuttgart 1	948	15 dBi (Azimuth 330°, 4° Downtilt)	7.9	35.70
Stuttgart 2	948	15 dBi (Azimuth 330°, 6° Downtilt)	5.0	35
Stuttgart 3	948	13.7 dBi (Azimuth 330°, no Downtilt)	6.3	29
Helsinki 1	900	omnidirectional	2.7	4
Helsinki 2	900	omnidirectional	2.5	4
Helsinki 3	2125	13.3 dBi (Azimuth 287°, Downtilt 7°)	10	41.50

Table 3: Scenarios and transmitters used for manipulation

Predictions with these scenarios are made and compared to the respective measurement campaigns. In the following, manual changes are applied to the databases in order to compute new predictions. The changes shall be explained by giving some examples:

A. Missing Corners

For simulation of inaccurate building outlines, up to 4 corners per building are manually removed at 10 buildings close to the transmitter. The example in figure 6 (transmitter marked green) shows the changes in the scenario Stuttgart 1.

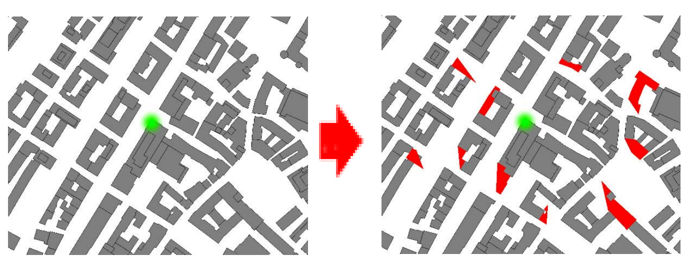

Figure 6: Removed corners in scenario Stuttgart 1

B. Shifted Buildings

5 to 7 buildings close to the transmitter are changed to simulate photometric inaccuracies. The buildings were moved arbitrarily in x- and y-direction, up to 30m per building. Figure 7 shows the changes in the scenario Stuttgart 1.

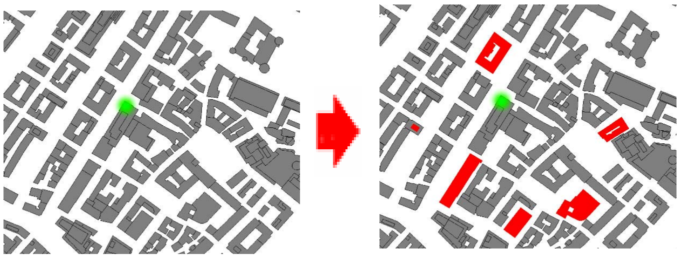

Figure 7: Shifted buildings in scenario Stuttgart 1

C. Removed Buildings

As strongest level of manipulation, a version of every database is created where 10 high buildings (height > 20m) are completely removed from the database. Due to their size, these buildings are expected to have long-distance effects, thus also buildings in some distance from the transmitter were taken into account. Figure 8 shows the removed buildings in the scenario Stuttgart 1.

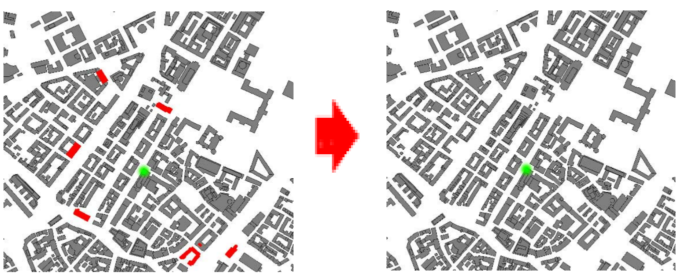

Figure 8: Removed buildings in scenario Stuttgart 1

Table 4 shows the differences observed between measurement campaigns and the predictions made with the original databases.

Prediction accuracy with the original database [dB]						
Datenbank	**IRT**		**UDP**		**COST**	
	ME	**SD**	**ME**	**SD**	**ME**	**SD**
München	-20,9	12,7	1,2	6,9	-12,8	7,0
Stuttgart 1	-2,0	10,5	-4,6	7,1	-5,4	7,6
Stuttgart 2	4,9	11,3	-2,2	9,4	-3,9	9,4
Stuttgart 3	-3,4	12,3	-12,8	12,7	-16,2	15,4
Helsinki 1	-9,9	8,9	-2,3	8,5	-17,5	13,0
Helsinki 2	-6,9	8,9	-0,9	6,7	-9,7	9,2
Helsinki 3	-8,3	9,9	-2,5	7,0	-9,4	12,1

Table 4: Prediction accuracy with original database

The averaged differences of all scenarios (both for the mean error as well as for the respective standard deviation) between the prediction based on the original database and the prediction made with the manipulated versions are shown in Table 5 and Table 6.

Averaged Difference of the Mean Error [dB]			
	IRT	**UDP**	**COST 231**
Missing Corners	+0.7	+0.2	+0.1
Shifted Buildings	-1.0	+0.2	+0.1
Removed Buildings	+0.7	+0.2	+0.1

Table 5: Averaged difference of the mean error

Averaged Difference of the Standard Deviation [dB]			
	IRT	**UDP**	**COST 231**
Missing Corners	0.0	+0.1	+0.1
Shifted Buildings	+1.0	+0.2	0.0
Removed Buildings	+0.1	-0.1	0.0

Table 6: Averaged difference of the standard deviation

Figure 9 graphically shows the difference between Ray Tracing and Dominant Path model: Whilst with Ray Tracing, severe differences between the predictions occur – especially in the case of shifted buildings – the Dominant Path model shows only very small changes in the predictions. The COST 231 Walfisch-Ikegami model is the most robust model amongst the three, yet under the premise that its predictions are a priori less accurate.

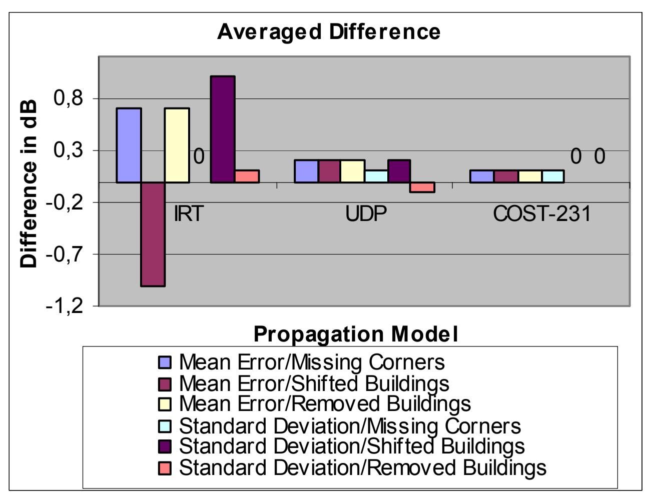

Figure 9: Averaged Difference

V. Simplification of Building Databases

A. *The Simplification Tool*

The investigated tool [6] performs a simplification of building databases using several kinds of reductions, i.e. the removal of redundant building corners or buildings below a predefined height, the combination of adjacent buildings and a smooth reduction of corners on each single building. The computational effort of the simplification is very low, so it can be neglected in the consideration of computation times.

B. *Settings*

The parameter sets for the different simplification settings are given in Table 7.

	Level 1 (slight)	Level 2 (medium)	Level 3 (strong)	"Corners"	"Combi-nation"
Removal of buildings lower than	1m	3m	5m	-	1m
Removal of redundant corners	yes	yes	yes	yes	yes
Corner reduction level	-	10	20	40	-
Comb. of adjacent buildings, max. rel. height diff.	-	-	10%	-	25%

Table 7: Simplification – parameter sets

As scenarios, the above mentioned configurations of Munich and Stuttgart are used including the respective measuring campaigns.

C. *Results*

There is hardly any reduction of computation time for the Dominant Path and the COST 231 Walfisch-Ikegami models due to their approach and their fast algorithms. In the case of Ray Tracing, things turn out different. As an example, table 8 shows the changes of calculation times for the Intelligent Ray Tracing model in the Munich scenario Both the required time for the building database preprocessing [5] as well as the prediction time are shown.

Computation Times for IRT in Scenario Munich (Preprocessing/Prediction) [s]						
Database Version	Original	Level 1	Level 2	Level 3	"Corners"	"Combination"
Computation Times	6207/42	6156/36	5175/32	4431/30	4011/24	5860/35

Table 8: Computation times for IRT in scenario Munich

The averaged results for all investigated scenarios for the Ray Tracing model are displayed in Table 9.

Changes due to simplifications in IRT simulations					
	Level 1	Level 2	Level 3	„Corners“	„Combination“
Comput. Time	-16%	-21%	-47%	-28%	-18%
Mean Err. (abs.)	+0.1 dB	+0.5 dB	+1 dB	+0.5 dB	+1 dB
Standard Dev.	+0.1 dB	+0.1 dB	-0.1 dB	-0.5 dB	+0.7 dB

Table 9: Results of database simplification

These results show that a significant reduction of calculation times (up to 50 percent) is possible when using the Intelligent Ray Tracing model and accepting a small drop in accuracy. These results certainly also apply to other Ray Tracing models.

VI. Conclusion

The results presented in this paper show a clear advantage of the Dominant Path model in terms of robustness against database inaccuracies. This is of importance especially in cases where economic considerations prevent the use of maximum-precision vector data, or when older databases should be used.

Furthermore, the simplification tool offers a new possibility for reducing calculation times of Ray Tracing, without losing a great deal of precision. The tool will be further developed, so it might yield even better results.

Similar investigations are in process for indoor propagation models. First results show a similar behavior as in urban scenarios.

References

[1] R. Wahl, G. Wölfle, P. Wertz, P. Wildbolz, *Dominant Path Prediction Model for Urban Scenarios*, 14th IST Mobile and Wireless Communications Summit, Dresden (Germany), June 2005.

[2] N.C. Goncalves, L.M. Correia: *A propagation model for urban microcellular systems at the UHF band*, IEEE Transactions on Vehicular Technology, Volume 49, Issue 4, July 2000, pp. 1294 – 1302.

[3] V. Degli-Esposti, A. de'Marsi, F. Fuschini: *A field prediction model for urban environment based on pattern recognition and statistical ray tracing*, 53rd Vehicular Technology Conference (VTC), 2001 - Spring, Rhodos (Greece), Volume 1, 6-9 May 2001, pp. 428 – 432.

[4] G. Wölfle, B. E. Gschwendtner, F.M. Landstorfer, *Intelligent ray tracing - A new approach for the field strength prediction in microcells,* 47th Vehicular Technology Conference (VTC) 1997 - Spring, Phoenix, Arizona, USA, pp. 790-794, May 1997.

[5] R. Hoppe, G. Wölfle, F. M. Landstorfer, *Fast 3D Ray Tracing for the Planning of Microcells by Intelligent Preprocessing of the Database*, 7th COST 259 MCM-Meeting in Thessaloniki, Greece, COST 259, TD (99) 006, January 1999.

[6] Winprop Software Suite, documentation and trial version at www.awe-communications.com.

[7] Editors: E. Damosso, L.M. Correia: *COST 231 Final Report, "Digital mobile radio: COST 231 view on the evolution towards 3 rd generation systems"*., European Commission – COST Telecommunications, Brussels, Belgium, 1998.

[8] K. Rizk, J.-F. Wagen, F. Gardiol: *Influence of Database Accuracy on Two-Dimensional Ray-Tracing-Based Predictions in Urban Microcells*, IEEE Transactions on Vehicular Technology, Volume 49, Issue 2, March 2000, pp. 631 – 642.

[9] G. E. Athanasiadou, A. R. Nix: *Investigation into the Sensitivity of the Power Predictions of a Microcellular Ray Tracing Propagation Model*, IEEE Transactions on Vehicular Technology, Volume 49, Issue 4, July 2000, pp. 1140 – 1151.