INDOOR PROPAGATION MODELLING IN MULTI-STOREY BUILDINGS IN PRAGUE

Pavel Pechač, Martin Klepal, Miloš Mazánek

Czech Technical University in Prague
Department of Electromagnetic Field
Technická 2, 166 27 Praha 6, Czech Republic
Email: pechac@ieee.org

INTRODUCTION

For the design and maintenance of indoor wireless services the knowledge of the signal propagation in different environments is demanded. Indoor propagation is one of the most complicated propagation topics based on the specific type of the building structure and used materials. Empirical modelling based on statistics seems to be the most efficient approach since there is no need of precise definition of the building interiors. On the other hand, such models can failed in anomalous indoor situations where more precise site-specific model should be used, e.g. ray tracing. Such a anomalous case - small shielded chamber inside a room - was studied. Evens so there are many studies (e.g. [4][5]) dealing with empirical models for indoor propagation the results can be hardly used for city of Prague without modifications. There are several specific architecture styles and used materials. The paper describes the indoor propagation measurement campaigns in the frequency range of 900 MHz done in two multi-storey university buildings, which are typical for Prague. The first one is a modern nine-storey building made with concrete skeleton with large windows (Fig. 1). A central heating is integrated into floors. The second four-storey building is the older one made from bricks with high ceilings and wide corridors. There were large metal cases along both sides of the corridors. There are offices, laboratories and lecture rooms in both of the buildings. Based on the measurement results the easy-to-use empirical propagation prediction model was derived.

MEASUREMENT SYSTEM

For the measurement campaign a special measurement device set was designed. The measurement system consists of the measurement transmitter [1] and the measurement receiver [2] with automated data collection. Table 1 presents the parameters. 900 MHz signal AM modulated by 1 kHz was transmitted by a vertically polarised quarter-wavelength monopole omnidirectional antenna at a height of 2 m above the floor. Folded dipole - the mobile receiver antenna - was turned for 45 grades from vertical direction to receive both vertical and horizontal polarisation and to simulate mobile phone position. The mobile antenna was moving in a walking speed at a height of 1.5 m above the floor.

Table 1. Transmitter and receiver parameters

frequency band	870 - 999 MHz, 1 MHz step
frequency stabilisation	PLL
transmitter output power	30 dBm +/- 0.5 dB, ALC loop
modulation	1 kHz AM square wave
measurement bandwidth	0.3 MHz
receiver input signal range	-30 to - 90 dBm
A/D converter	12 bit, parallel output
receiver resolution	min. 0.1 dB

MULTI-FLOOR MODEL

For the multi-floor propagation modelling the basic empirical modelling approach proposed by Motley and Keenan [6] with linear dependence of the floor attenuation was used:

$$L(d) = L_0 + 10n\log d + kF_1 \qquad (1)$$

where $L(d)$ is the path loss in the distance d [m] from the transmitter [dB]
L_0 attenuation in reference distance 1 m obtained as a free space propagation [dB]
n path-loss exponent
k number of floors between transmitter and receiver antennas
F_1 single-floor propagation attenuation (floor loss factor) [dB].

Some authors (e.g. [4]) report non-linear dependence of the floor attenuation:

$$L(d) = L_0 + 10n \log d + F_k \tag{2}$$

where F_k is propagation attenuation through k floors between transmitter and receiver antennas [dB].

That is why we tried to derive n and F for both models. Fig. 1 shows the structure of the Building I with the transmitter location and receiver antenna paths in each floor. All the paths were same lengths of 40 m in the corridor with no other obstacles between the transmitter and receiver antennas. The measurement arrangement for the Building II was similar. The model parameters for both of the models were retrieved from the measured data set minimising the mean square error. Table 2 and Fig. 2 present the results. As it can be seen, for both building types a satisfactory accuracy can be achieved using simpler model (1) with linear floor loss factor. The average attenuation for single floor for model (2) was 6.9 dB for Building I and 10.9 dB for Building II. Path loss exponent n indicates a strong waveguide effect in corridors especially in Building II caused by metal cases mentioned above. All the measurements were repeated several times in different parts of the day. The derived model parameters and standard deviations were changing within 1 dB regardless of number of people in offices and corridors.

Table 2. Model parameters and standard deviations

Model	n	F_1	F_2	F_3	F_4	F_5	F_6	standard deviation
Building I, Model (1)	1.8	7.4						5.2
Building I, Model (2)	1.8	4.5	14.6	23.5	30.9	35.6	41.2	5.0
Building II, Model (1)	0.9	11.7						4.3
Building II, Model (2)	0.9	10.7	25.3	27.7				4.1

PARTITION ATTENUATION MODEL

When there are walls in a direct path between transmitter ant receiver antennas model (1) can be expanded to include additional site-specific losses:

$$L(d) = L_0 + 10n \log d + kF_1 + \sum_{i=1}^{M} A_i \tag{3}$$

where M is the number of partitions between transmitter and receiver antennas
A_i attenuation factor for i-th partition [dB].

Free space propagation $n = 2$ is often used in (3), e.g. COST 231 Multi-Wall-Model. In some situations this approach cannot consider waveguide effects in corridors. That is why we used n values derived from multi-floor propagation measurements. Parameter F_1 was taken from the model (1) as well. From the measured data set the constants A for model (3) are derived according to building and partition types. There is a good agreement for such a prediction with measurements for regular interiors of the building. The question is the model validity for some anomalous objects. Fig. 3 shows the floor plan with anechoic shielded chamber (7.1 × 4.4 × 3.2 m) located in the room L5 together with partition types and corresponding attenuation factors A from (3) derived for the whole floor measured data set. Note the factor A = 5.4 dB for a metal sheet. It is obvious that the parameter is rather statistical value than a real material attenuation. The standard deviation for all locations was 6.9 dB and it varies from 5.0 to 7.5 dB for particular parts of the floor. It proved us a usability of the model for whole building regardless of the anomaly in L5 during the measurements for model parameters extraction. Of course, more studies of different anomalous situations should be carried out to make a more general conclusion.

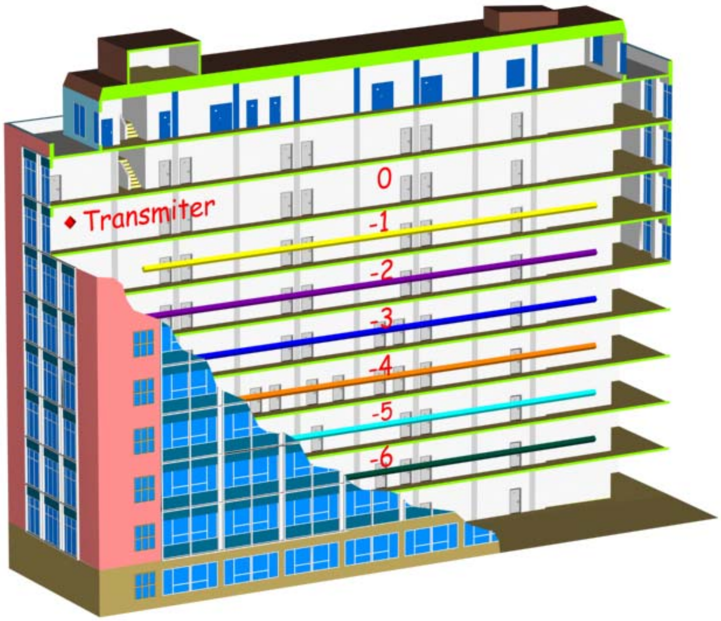

Fig. 1. Building I structure with measurement paths of the receiver antenna in each floor

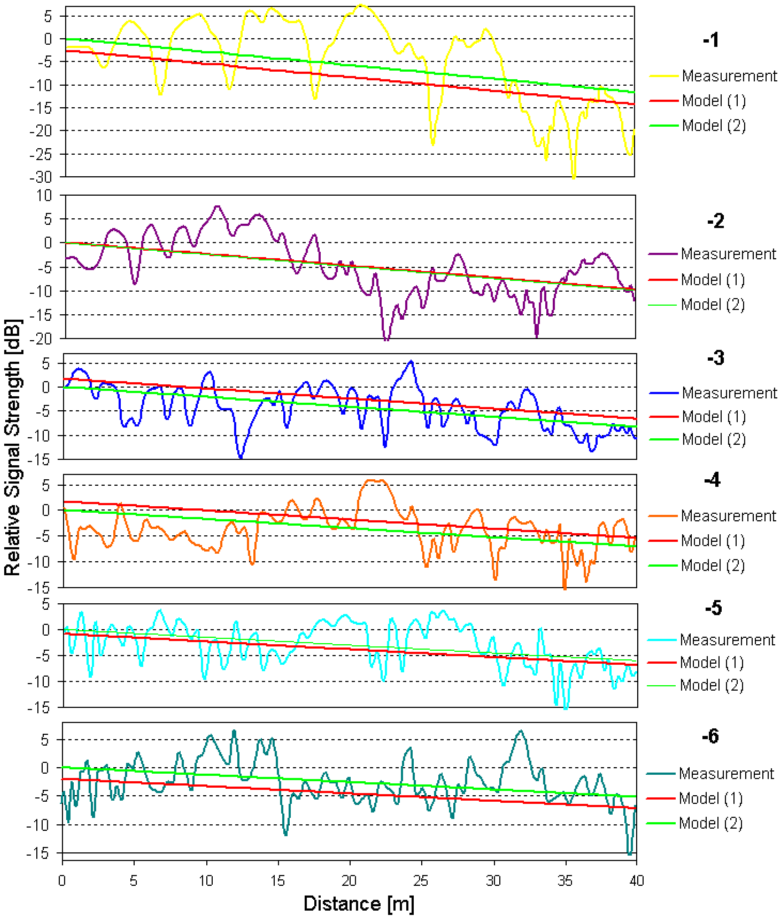

Fig. 2. Multi-floor propagation measurement results versus the model predictions in each floor for Building I

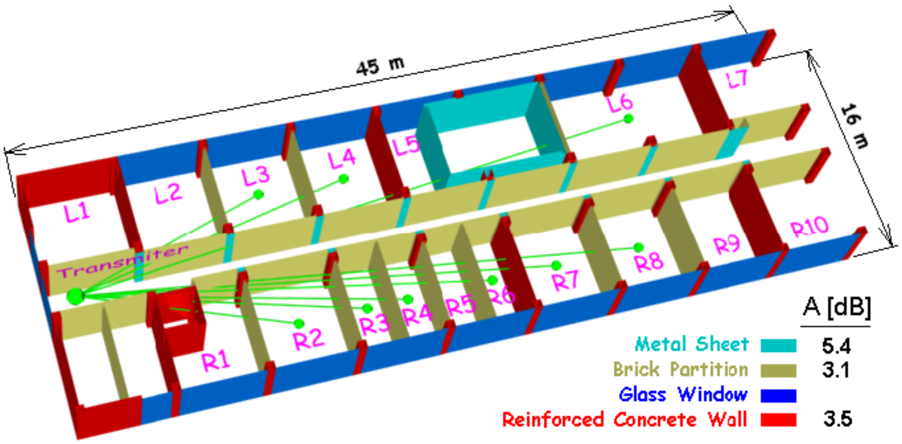

Fig. 3. Floor plan for single-floor measurements and modelling with room numbers and direct ray examples

CONCLUSIONS

Familiar empirical model was adopted for two typical buildings in the city of Prague. Variations of the model were studied and following conclusions for the two building types stated:

- linear dependence of the floor attenuation (1) was observed
- model (3) with parameters given in Tab. 2 and Fig. 3 can be used with satisfactory accuracy for whole building
- model (3) parameters n and F_1 can be generated from measurements carried out just in corridors
- anomalous objects similar to shielded chamber in L5 (Fig. 3) do not severely degrade the model validity
- number of people in rooms and corridors does not influence the model validity.

The models described above are being implemented into a CAD software tool for complex design of indoor cellular systems. It is possible to optimise model parameters according to additional test measurements. Interference issues must be considered for cellular systems. For a frequency plan synthesis and optimisation the routines based on genetic algorithms will be adopted from the software developed for outdoor frequency planning [6].

The project continues using a similar approach for other frequency bands. Measurement systems at the frequency ranges of 1800 MHz and 2.45 GHz are under development. A lot of measurements in various locations should be accomplished to provide a full set of general models with sufficient validity for majority of buildings in Prague. In the same time other novel ways of semi-empirical modelling of indoor propagation are searched.

REFERENCES

[1] P. Hájek: “Measurement transmitter 900 MHz,” *Diploma Thesis,* Czech Technical University in Prague, Department of Electromagnetic Field, Prague 1997.

[2] D. Dedek: “Measurement receiver 900 MHz,” *Diploma Thesis,* Czech Technical University in Prague, Department of Electromagnetic Field, Prague 1999.

[3] A.J. Motley and J.M.P. Keenan: “Personal Communication Radio Coverage in Buildings at 900 MHz and 1700 MHz,” *IEE Electronics Letters*, vol. 24, no. 12, pp. 763-764, 1989.

[4] Y.S. Scott and T.S. Rappaport, “914 MHz Path Loss Prediction Models for Indoor Wireless Communications in Multifloored Buildings,” *IEEE Trans. on Antennas and Propagation*, vol. 40, no. 2, pp. 207 - 217, February 1992.

[5] F.C. Owen and C.D. Pudney, “In-Building Propagation at 900 MHz and 1650 MHz for Digital Cordless Telephones,” *ICAP ’89 University of Warwick,* vol. 2., pp. 276 - 280, IEE, April 1989.

[6] P. Pechač: “Propagation of Electromagnetic Waves for Mobile and Personal Communications,” *Doctoral Thesis,* Czech Technical University in Prague, Department of Electromagnetic Field, Prague 1998.

ACKNOWLEDGEMENT

This project has been supported by grant of Grant Agency of the Czech Republic No. 102/99/D099 “Indoor Propagation for Wireless Personal Communication Systems“.