EMPIRICAL MODELS FOR INDOOR PROPAGATION IN CTU PRAGUE BUILDINGS

Pavel Pechač, Martin Klepal
Department of Electromagnetic Field
Czech Technical University in Prague
Technická 2, 166 27 Praha 6
Czech Republic

Abstract

Indoor propagation modelling is demanded for the design and maintenance of indoor wireless services. Empirical modelling seems to be the most efficient approach. Evens so there are many studies dealing with empirical models for indoor propagation the results can be hardly used for local buildings without modifications. There are several specific architecture styles and used materials. The indoor propagation measurement campaigns in the frequency range of 900 MHz were done in two typical multi-storey university buildings in Prague. Based on the measurement results the easy-to-use empirical propagation prediction models were derived for both of the buildings with satisfactory accuracy. Variations of the models were studied. The models are being implemented into a CAD software tool for complex design of indoor cellular systems. The project continues using a similar approach for other frequency bands. In the same time other novel ways of semi-empirical modelling of indoor propagation are investigated.

Keywords

indoor propagation, electromagnetic waves, modelling, measurement, personal wireless systems

1. 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 [9]. Such an anomalous case - small shielded chamber inside a room - was also studied. Evens so there are many studies (e.g. [5][6][7]) 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.

2. Measurement

The indoor propagation measurement campaigns in the frequency range of 900 MHz were done in two typical multi-storey university buildings in Prague.

2.1 Measurement system

Special mobile measurement system was developed [2]. The 900 MHz measurement system consists of the measurement transmitter [3] and the measurement receiver [4]. The parameters are listed in Table 1. The main purpose of the system is to simulate an average GSM radio link and measure signal levels at required locations. Output data can be directly read and stored with the help of the PC. During any measurement the system must not disturb the regular GSM service.

The transmitter consists of the VCO and the PLL unit, the buffer amplifier stage, the modulator and ALC stage, the driver amplifier and the power amplifier. With the help of the transmitter tunability, PLL frequency stabilization and 1 MHz frequency step it is always possible to ensure that the measurement will not interfere with any standard service. The square wave amplitude modulation improves receiver sensitivity and its immunity against interference. The 217 Hz pulse modulation can simulate GSM signals. The transmitter can be powered from 220 V AC line or from the 12 V DC battery, its power consumption is approx. 25 VA.

The measurement receiver consists of an input tunable filter, pre-amplifier, mixer, 10.7 MHz IF amplifier, logarithmic amplifier and the A/D converter. The VCO frequency is stabilized with the help of the PLL circuit, receiver input frequency can be set from the control PC. The IF amplifier is followed by a logarithmic amplifier with min. 60 dB signal level range. Since the required output format is digital, all following signal processing is performed by a 12 bit A/D converter and the specialized control SW. The measurement receiver can be directly connected to the PC (notebook) parallel port.

The signal 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.

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

Table 1. Transmitter and receiver parameters

2.2 Locations

The first building (Building I) is a modern nine-storey building made with concrete skeleton with large windows (Fig. 1). The partitions are made from bricks or concrete. Measured corridors are about 3 m wide. A central heating is integrated into floors.

The second four-storey building (Building II) is the older one made from bricks with high ceilings and wide corridors. There were large metal cases along both sides of the corridors, which significantly influenced the measurement.

There are offices, laboratories and lecture rooms in both of the buildings. Both situations - empty interiors and corridors filled with people - were studied.

3. Models

The models were treated separately for the two basic modes: vertical multi-floor propagation and horizontal propagation within a single floor. Then the two models are combined in (3).

3.1 Multi-floor model

For the multi-floor propagation modelling the basic empirical modelling approach proposed by Motley and Keenan [5] with linear dependence of the floor attenuation was adopted:

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

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. [6]) report non-linear dependence of the floor attenuation:

$$L(d) = L_0 + 10n \log d + F_k \quad (2)$$

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, 3 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.

Location	n	F_1	standard deviation
Building I	1.8	7.4	5.2
Building II	0.9	11.7	4.3

Table 2. Model (1) parameters and standard deviations

Location	n	F_1	F_2	F_3	F_4	F_5	F_6	standard deviation
Building I	1.8	4.5	14.6	23.5	30.9	35.6	41.2	5.0
Building II	0.9	12.3	25.8	33.2				4.1

Table 2. Model (2) parameters and standard deviations

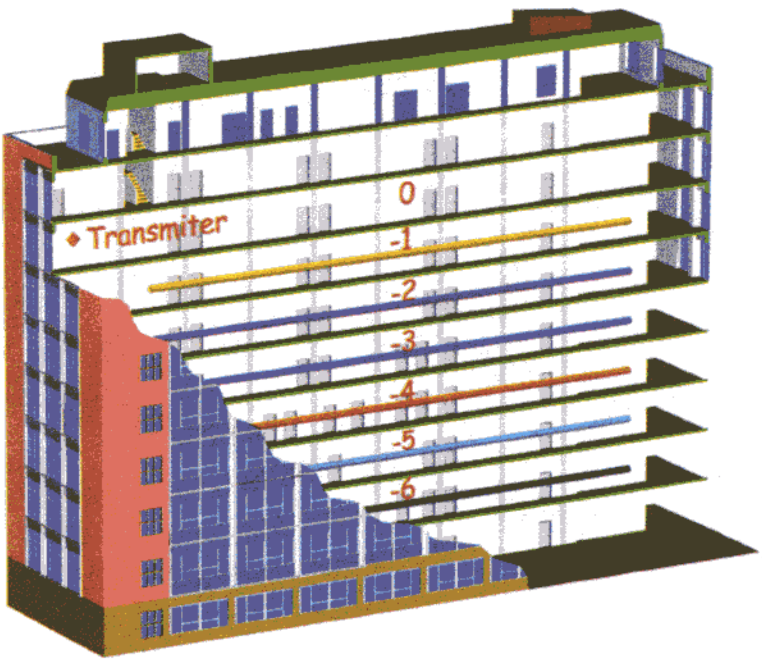

Fig. 1. Building I structure with measurement paths of the receiver antenna in each floor

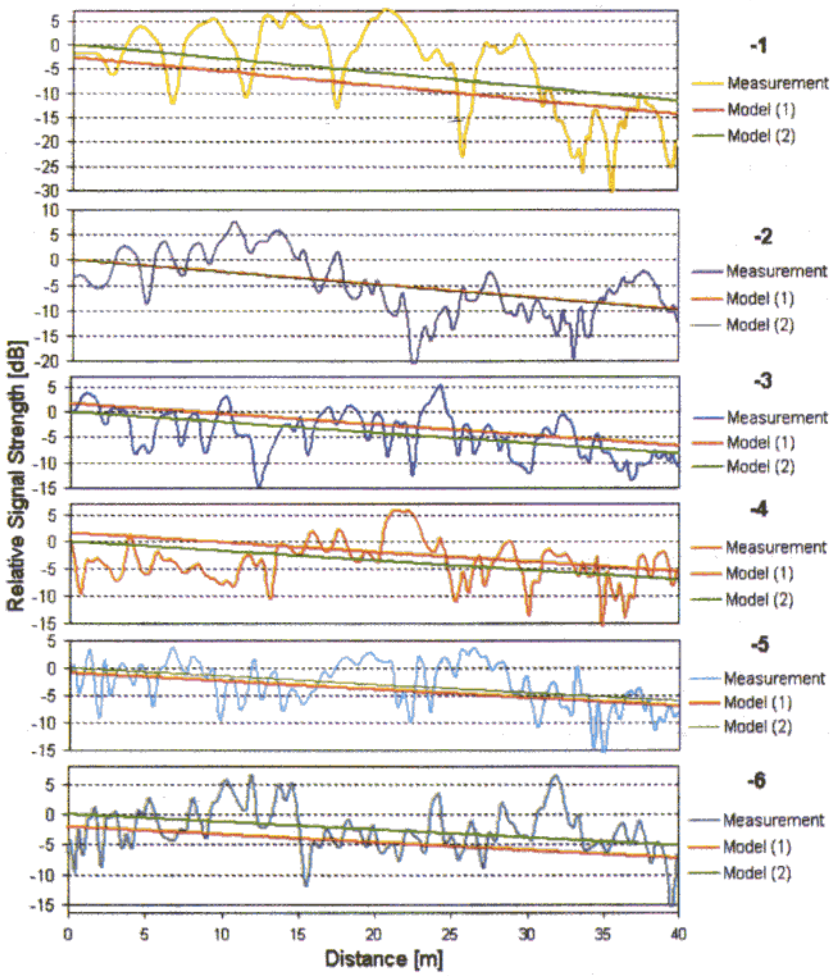

Fig. 2. Multi-floor propagation measurement results versus the model predictions in each floor for Building I

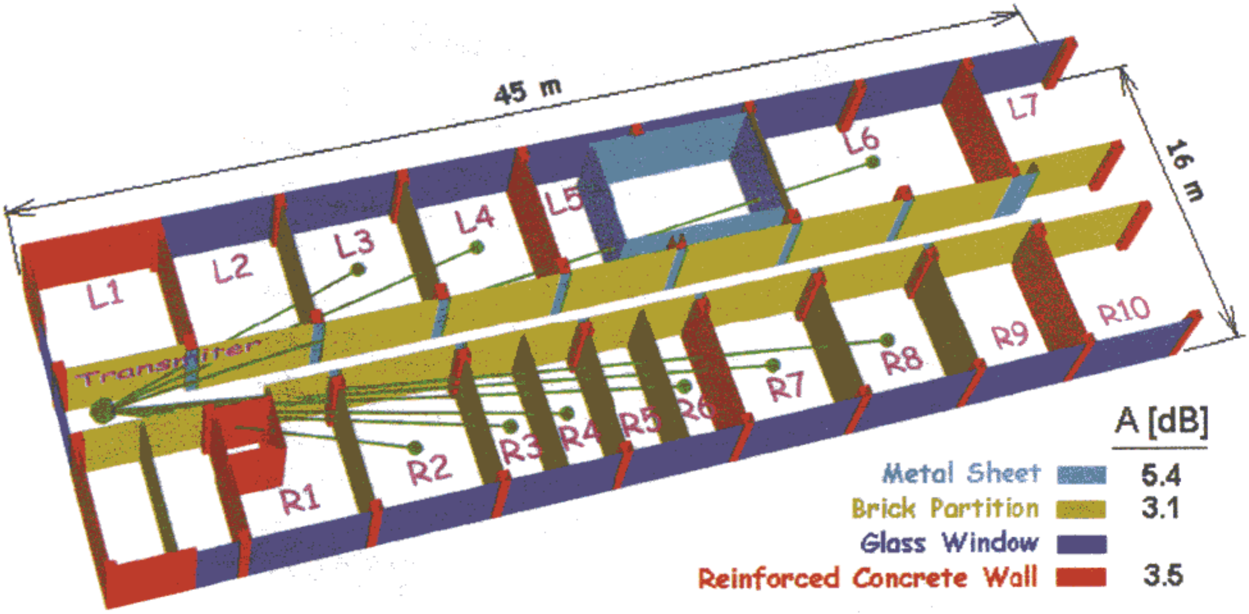

Fig. 3. Floor plan for single-floor measurements and modelling with room numbers and direct ray examples

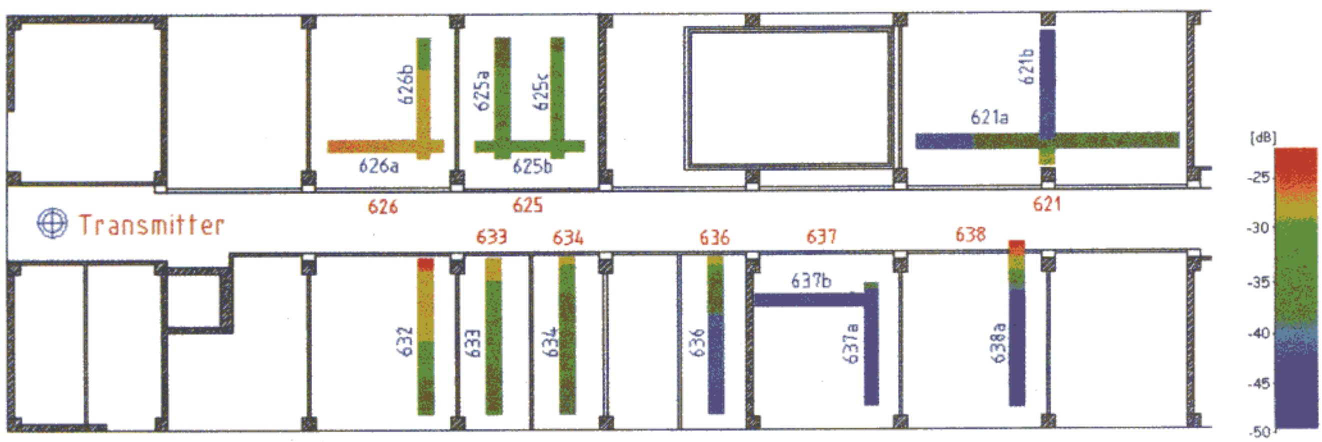

Fig. 4. Predicted relative field strength received when moving along straight lines
(red numbers represent room numbers, blue numbers indicate appropriate measurement data set)

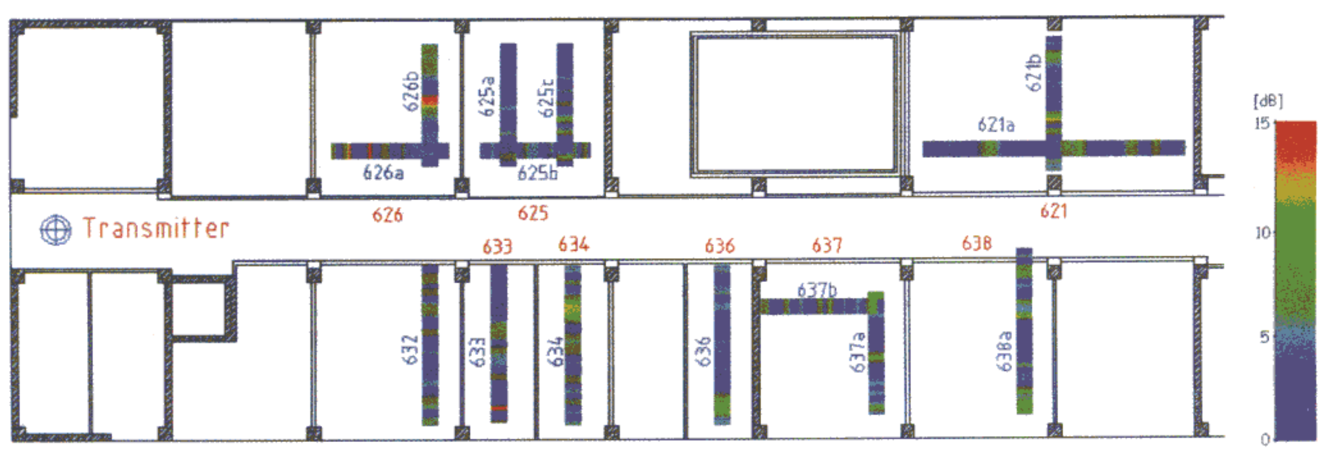

Fig. 5. Difference between measurement and prediction (red numbers represent room numbers, blue numbers indicate measurement data set)

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.

3.2 Partition attenuation model

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

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

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_l 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. Fig. 3 shows the floor plan and partition types with corresponding attenuation factors A derived for the whole floor from complete measured data set. The results of measurement and prediction together with their comparison are presented in the Fig. 4 and 5.

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.

4. CAD software tool

The models are being implemented into a CAD software tool for complex planning of indoor wireless systems. It is possible to optimise model parameters according to additional test measurements.

Interference issues must be considered for complex design 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 [11]. For automation of optimal base station transmitters placement both the sufficient field strength coverage and interference conditions must be taken into account.

5. 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_l 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 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] Klepal, M.: Šíření signálu 900 MHz uvnitř zástavby. Bakalářská práce, FEL ČVUT K317, 1998

[2] Pechač, P. - Mazánek, M. - Hudec, P. - Macháček, M.: 900 MHz Signal Attenuation Measurement for Mobile Wireless Communications in Urban Area. Radioelektronika 98, Brno 1998, str. 285-288

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

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

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

[6] Scott, Y.S. - Rappaport, T.S.: 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.

[7] Owen, F.C. - Pudney, C.D.: 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.

[8] Wolfle, G. - Wertz, P. - Landstorfer, F.M.: Performance, Accuracy, and Generalization Capability of Indoor Propagation Models in Different Types of Buildings, 10th IEEE Internat. Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC) 1999, Sept. 1999, Osaka, Japan F5-2

[9] Wölfle, G. - Hoppe, R. - Landstorfer, F.M.: Radio Network Planning with Ray Optical Propagation Models for Urban, Indoor, and Hybrid Scenarios, Radio and Wireless Conference (RAWCON) 1999, Denver, August 1999, pp. 159-162

[10] Faruque, S.: Cellular Mobile Systems Engineering, Artech House, London, 1996.

[11] Pechač, P.: 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".

About authors...

Pavel Pechač was born in 1970 in Prague, Czech republic. He graduated at the Czech Technical University in Prague, Faculty of Electrical Engineering in 1993. He received Ph.D. degree in Radioelectronics in 1999 at the Department of Electromagnetic Field. He is employed at the department as an assistant professor. His research interests are in the field of antennas and propagation in modern wireless systems. Recently he is mainly focused on indoor propagation.

Martin Klepal was born in 1975 in Kolin, Czech republic. He is a student of the Czech Technical University in Prague, Faculty of Electrical Engineering. He received BS.C. degree in Radioelectronics in 1998 at the Department of Electromagnetic Field. He also works at the department in the frame of the "Antenna Laboratory" project. His main research interest is an indoor propagation modelling.