Paper

# Characteristics of the indoor propagation channel in 1.9 GHz band

Krzysztof Kurek, Dariusz Janusek, Tomasz Kosiło, and Józef Modelski

**Abstract — This paper presents results of propagation measurements carried out in the frequency range 1.8 – 2.0 GHz inside a building, using network analyser. Wideband properties of the channel, described through mean delay and delay spread, and a narrowband local statistics of the received power have been presented. For each transmitter and receiver antennas location two propagation cases have been considered, line of sight (LOS) and obstructed line of sight (NLOS) – the direct path component was attenuated by radio absorbing mat near the receiver.**

***Keywords — indoor propagation channel, channel impulse response, time dispersion.***

## 1. Introduction

In last years the number of mobile system applications is growing very fast. Such systems as cellular (GSM 900, GSM 1800) and cordless (DECT, PHS) are widely used, the next generation cellular system (UMTS 2000) is planed for the year 2002 [4]. WLAN and ISM (e.g. Bluetooth [5]) systems are also extensively developed. In many situations those systems will be used in highly urbanised areas and inside buildings. Indoor signal propagation strongly depends on building configuration and material used. The received signal is a sum of multipath components reflected, diffracted and diffused on surrounding objects (walls, obstacles, etc.). Because amplitude, phase and delay of each component changes very fast as a result of terminal movement (or movement of surrounding objects, peoples in building for example) the received signal fluctuates. For narrowband observation the main result is fading – variation of the signal strength, and for wideband observation time dispersion, causing intersymbol interferences is the main effect. The more detailed description of indoor propagation can be found in literature e.g. [1 – 3].

The knowledge of the propagation channel properties is necessary for a communications system design allowing determining maximal signal bandwidth, kind of equalisation in receiver and transmitter locations as well. The problem of effective indoor channel measuring and modelling is discussed in many papers e.g. [6 – 10]. This paper presents results of the channel measurements, in 1.9 – 2 GHz band. We were mainly interested in the influence of direct ray on channel properties. After description of measurement procedure, wideband characteristics of the channel and the narrowband statistics of the received power variations are presented. Conclusions are presented at the end.

## 2. Procedure of measurements

The wideband channel propagation characteristics were measured in frequency domain, by use of HP8720C vector network analyser [6]. Block diagram of the measuring system is presented in Fig. 1. An output signal from the analyser (output power −10 dBm) is connected to the transmitting antenna through 6 m coaxial cable. Signal from the receiving antenna is amplified by additional 35 dB amplifier and sent through 24 m cable to analyser input. The 2 dBi omnidirectional, vertical polarised antennas, placed at 1.3 m height over the floor were used for transmission and reception.

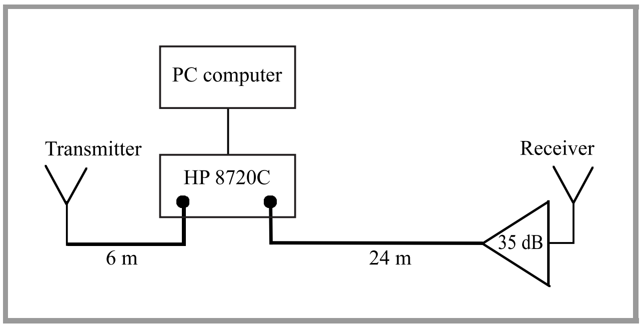

*Fig. 1.* Block diagram of the measuring system.

The direct measurements result was channel transfer function. The channel impulse response was calculated, using IFFT, with 5 ns time resolution. It means that all multipath components that reached the receiver antenna in 5 ns time interval are shown as one impulse whose amplitude depends on vector sum of these components. Measurements were done in the building of the Faculty of Electronics and Information Technology, Warsaw University of Technology at two locations: in a laboratory room (5.5 m wide and 6 m long) and in a corridor (2.6 m wide and 30 m long). The external walls of those places are concrete with glass windows, internal walls are of brick. For each measuring session the transmitting antenna ($Tx$) was fixed, and the receiving antenna ($Rx$) was moved along lines parallel to walls:

- in the laboratory room along two lines: towards the $Tx$ antenna and perpendicular to them;
- in the corridor along line towards the $Tx$ antenna only.

For each $Rx$ antenna location two types of propagation were arranged: LOS and NLOS. The direct ray was attenuated by putting radio wave absorbing plate (Laminated absorber AEL – 4.5, of Advanced ElectroMagnetic INC., dimensions $0.6 \times 0.6$ m, reflection attenuation $> 20$ dB, for freq. $>$ 0.6 GHz) in front of the receiving antenna.

We characterise the channel dispersive properties by typical parameters: mean delay and delay spread, calculated from the power delay profile [1]. The following assumptions have been done during measured data treatment:

a) threshold level 30 dB below maximum component of the impulse response is assumed; e.g. all the smaller values are treated as noise and are not taken into analysis;

b) the impulse response delay is defined relatively to the first component (first received path).

## 3. Analysis of results

Typical examples of measured propagation channel transfer functions and normalised impulse responses for LOS and NLOS situation are presented in Fig. 2. Both impulse responses are normalised to the level of non obstructed direct ray for LOS. During NLOS direct ray is attenuated because of that a relative level of multipath components in the received signal is larger and channel is more time dispersive. Additionally received power for this case is smaller. Changes of the channel properties for LOS and NLOS situations are especially large for small distances between $Tx$ and $Rx$ antennas, when amplitude of non attenuated direct ray is dominant in the received signal (about 20 dB above multipath components for distances $1-2$ m). Figure 3 shows average values of these dispersive parameters for the propagation in laboratory room. Attenuation of LOS component causes an increase of average mean delay from 6 ns to 10 ns and average delay spread from 8.8 ns to 10.7 ns. In the case of measurements at the corridor average values are respectively 10.8 ns and 23.4 ns, and after LOS ray obstruction average mean delay changed to 14.1 ns and average delay spread to 29.1 ns. Values of dispersive parameters also depend on distance between transmitter and receiver antennas, local average values of them are larger with increasing of distance.

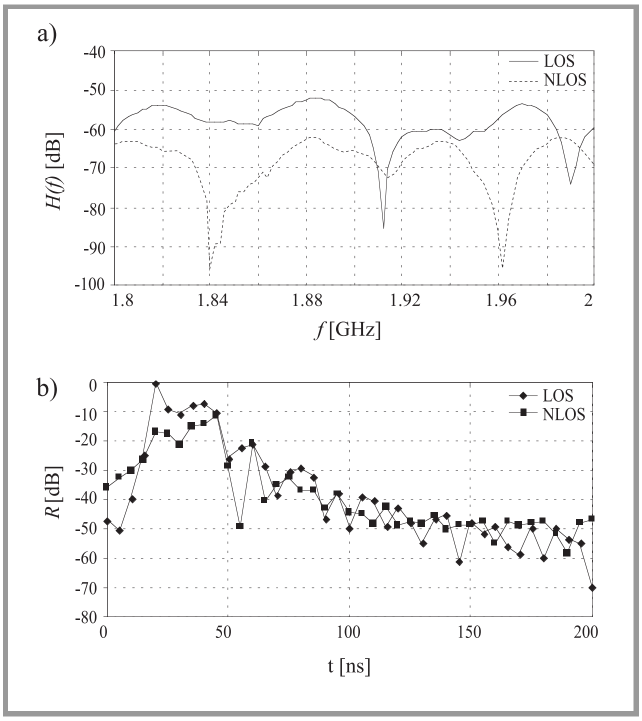

***Fig. 2.*** Transfer functions (a) and normalised impulse responses (b) of the propagation channel for LOS and NLOS situations.

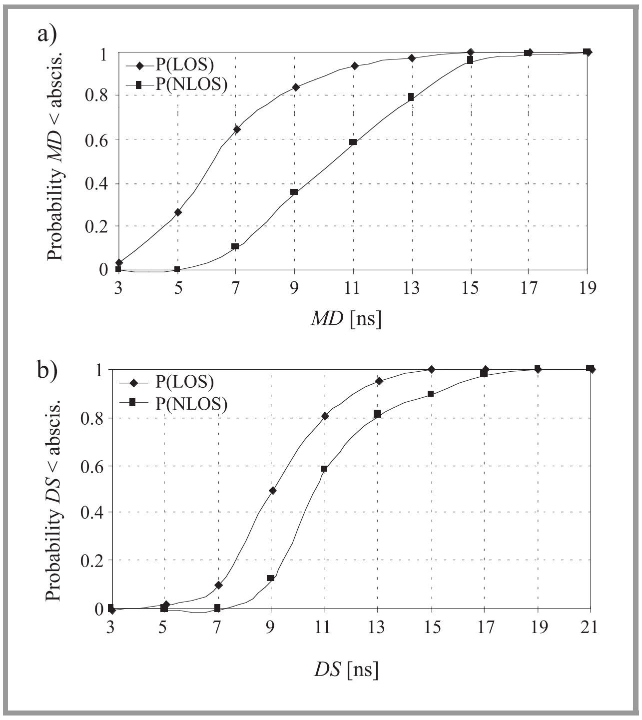

***Fig. 3.*** Cumulative probability distributions of the mean delay (a) and delay spread (b) for measurements in laboratory room.

Figure 4 shows the average power delay profiles for two analysed places. That curves were calculated from all the measurements for the laboratory and the corridor respectively. The laboratory profile is very regular. At the corridor profiles there are two strong components: a) first (direct) component which is a sum of direct ray and rays reflected from walls and floor with delay less than the time resolution of measurements (because the corridor is long and narrow); b) large amplitude multipath component with delay 100 ns, which is caused by a ray reflected from the metal door at one end of the corridor.

In Fig. 4 the aproximation of the delay profiles by a simple exponential function is also shown. The laboratory room propagation is modeled by the function $p(t) = e^{-mt}$, where $m$ is slope of the profile. For the LOS propagation case $m$ is $-1.2$ and for NLOS situation $m$ is $-0.8$. The

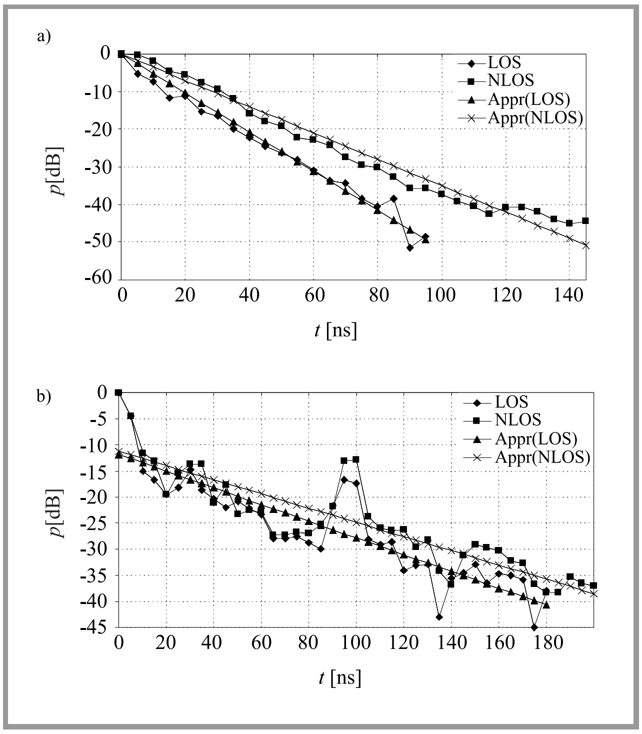

***Fig. 4.*** Average power delay profiles of the propagation channel and their exponential approximations: (a) for laboratory room; (b) for corridor.

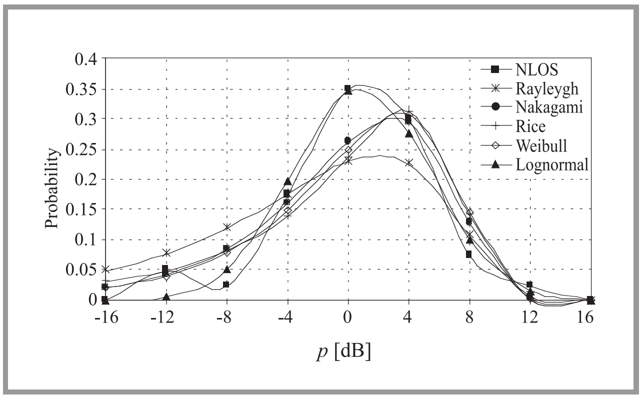

***Fig. 5.*** Probability density function of the received power for NLOS situation and its approximations by commonly used distributions (with identical mean values and standard deviation).

corridor propagation is aproximated by a modified function $p(t) = k \cdot e^{-mt}$, where $m$ is 0.37 and $k$ is 0.066 for LOS, and $m$ is 0.31 and $k$ is 0.076 for NLOS situation.

Figure 5 presents an example of narrowband signal properties. We analysed the probability density function of received power at one frequency (1.9 GHz) from measurement taken at laboratory room. The receiving antenna was moved along a line parallel to the transmitter in 10 cm steps from wall to wall of the laboratory. The distance between the measuring line and the $Tx$ antenna was 6 m. Then statistics of the power variation normalised to the mean values have been calculated. For both LOS and NLOS situations local mean power changes with the receiver location, and obtained statistics are similar. Example of probability density function (PDF) of the received power at the frequency 1.9 GHz for NLOS situations is presented in Fig. 5, for comparison PDF's of common used distributions [7]: Rayleigh, Rice, Nakagami, Weibull, lognormal all with identical mean values and standard deviations are also shown. From our analysis its clear that for both LOS and NLOS situations, lognormal distribution best fits to experimental data.

## 4. Conclusions

Results of measurements for the indoor propagation channel in 1.9 GHz band have been presented. Wideband characteristics of the channel and the received power depend strongly on existence of visibility between antennas. Obstruction of line of sight path causes decrease of received power and increase of time dispersive properties of the propagation channel, especially for small distances between antennas. From our measurements there is a clear indication that in micro-cellular systems direct ray propagation situation should be preferred. That can be rather easy realised by putting base-station high on the walls or on a ceiling.

## References

[1] T. H. Rappaport, *Wireless Communications: Principles and Practices*. Piscataway: IEEE Press, 1996.

[2] G. L. Stüber, *Principles of Mobile Communication*. Boston: Kluwer, 1996.

[3] J. D. Parsons, *The Mobile Propagation Channel*. London: Pentech Press, 1992.

[4] R. Prasad, *Universal Wireless Personal Communication*. Boston/London: Artech House, 1998.

[5] Specification of the Bluetooth System, Bluetooth, July 1999. [Online]. Available WWW: www.bluetooth.com

[6] S. J. Howard and K. Pahlavan, "Measurement and analysis of the indoor radio channel in the frequency domain", *IEEE Trans. Instr. Measur.*, vol. 39, no. 5, pp. 751–755, 1990.

[7] H. Hashemi, "The indoor radio propagation channel", *Proc. IEEE*, vol. 81, no. 7, pp. 943–968, 1993.

[8] V. Erceg, S. J. Fortune, J. Ling, A. J. Rustako, and R. A. Valenzuela, "Comparisons of a computer-based propagation prediction tool with experimental data collected in urban microcellular environments", *IEEE Trans. Select. Areas Commun.*, vol. 15, no. 4, pp. 677–684, 1997.

[9] G. Wölfle, B. Gschwendtner, and F. M. Landstorfer, "Intelligent ray tracing – a new approach to the field strength prediction in microcells", in *IEEE 47th Vehic. Technol. Conf. (VTC)*, Phoenix, May 1997, pp. 790–794.

[10] A. J. Motley and J. M. Keenan, "Personal communication radio coverages in buildings at 900 and 1700 MHz", *Electron. Lett.*, vol. 24, no. 12, pp. 763–764, 1988.

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