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Research of IEEE 802.11 Standard Signal Propagation Features in Multi Floor Buildings

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***Abstract*—In this research paper, 802.11 g/n signals non line-of-sight propagation inside the multifloor building is examined. Tests were carried out to assess the signal losses under these conditions. The D-Link and Trendnet wireless routers were used as signal sources in experiments. The measurements were carried out by fixing the routers in the fourth floor of the building. The signal levels were measured with the spectrum analyzer in the 2, 3, 4 (line-of-sight conditions) and 5 floors of the building. The results were compared with the Motley-Keenan model. A new improved model, which allows assessing these experimental results more accurately, is proposed in this paper.**

***Index Terms*—Wireless LAN, MIMO, indoor radio communications, IEEE 802.11 standards.**

I. INTRODUCTION

Data transfer is one of the key components of the information society. Now users have a growing need for mobility, higher data transfer rates and reliability. Therefore, wireless communications are the field of telecommunications that are being most intensively developed nowadays.

It is relatively simple to design such network in an open space. However, a wireless network is often needed indoors, and the design of a good and reliable communication system inside the building requires much more effort, because signal strength is dependent on many factors, including the physical characteristics of buildings, their contents, etc. This task becomes much more complicated due to the need to have a wireless connection at any place inside the building. In order for the project to be optimized, the building cannot be overloaded with wireless network access points. Otherwise, network management becomes more complicated, the cost of the project increases, and the electromagnetic field interferes with both the existing and new wireless technologies (Bluetooth, NFC, etc.).

Wireless systems operate under line-of-sight (LOS) or non–line-of-sight (NLOS) conditions inside the building. However, in practice, systems operate under NLOS conditions. The main problem is that it is very difficult to predict the propagation of radio waves between the transmitter and the receiver in the NLOS situation Thus, there is a need for models that enable to assess and predict the signal propagation in different environments as accurately as possible.

The aim of this paper is to investigate the 2.4 GHz frequency signal propagation under NLOS conditions in the multifloor building and to propose adjustment factors for the selected model.

These experiments are still highly important because radio wave propagation is very difficult to assess due to building distinctiveness (dimensions, wall differences, furniture, etc.). The number of this type of research studies carried out is relatively high but their results cannot be applied directly to all situations. There is also a lack of research studies on the 802.11n and new standards. Therefore, all results are very important for further adjustment of the existing models or for the development of new predictive models. This paper is also a continuation of the previous papers [1]–[3] aimed at clarifying the 802.11 standard signal propagation in the same building just under LOS conditions and the impact of walls on signal propagation losses.

II. OTHER EXPERIMENTS AND MODELS

A. *Experiments*

There are currently quite a lot of experiments conducted to assess the signal levels at certain points of buildings, where the signal is transmitted on the same floor under LOS and NLOS conditions. However, there is a lack of data on the impact of the floor on the propagation of such signals, especially using new (e.g., MIMO) technologies.

The impact of floors of a building was investigated in the study [4], where the access point was placed on one floor, and the investigations were carried out on the floors below and above. The experimental data were compared with the log-distance model. The n values (n = 4 for the upper floor and n = 3.22 for the lower floor), indicate a sufficiently large impact of NLOS conditions on signal losses.

The paper [5] proposed three new models for assessing different situations where a signal is transmitted under NLOS conditions. These models are basically traditional free-space path losses models with one or two additional factors that need to be determined experimentally by

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carrying out measurements in different situations. A similar model is proposed in the paper [6] as well.

The aim of the research study [7] was to assess the 802.11n standard signal propagation for indoor and outdoor situations. The characteristics of antennas and signal influencing factors were examined in this paper. It was aimed at creating, by combining theory with the actual measurements and using devices that support the IEEE 802.11n standard, a mathematical model which would allow predicting the 802.11n signal propagation.

The paper [8] analyses the 802.11b standard signal propagation in two-storey buildings. The results are compared with three models, which are essentially the modifications of the log-distance model and allow evaluating the exponent n. The exponent n, depending on the model used, ranges from 3.9 to 5.2 on one floor below the access point, and from 3.7 to 4.9 where the difference is two floors. It is also shown that using the same model, the n value slightly depends on the number of the floor. Thus, according to the log-distance model, the exponent n, where the difference is two floors, equals 4.91, and 5.2, where the difference is one floor.

The damping factor of the floors is studied in [9] at a frequency of 1.25 GHz. Although the same models were used for data approximation, the obtained results were different from the results obtained in [8] due to different structural features of the buildings: under similar conditions the exponent n > 6.

B. Models

Results of indoor experiments are very often compared with the log-distance model or certain modifications of this model. This enables to evaluate certain effects which are mainly characteristic of closed spaces. Sometimes these models are used in open spaces as well. In this model, the average signal attenuation between the transmitter and the receiver is expressed as a function depending on the distance d and the damping factor n. The average signal path loss PL is expressed as follows

$$PL = PL(d) + 10n\lg\left(\frac{d}{d_0}\right), \tag{1}$$

where n is the damping constant, which indicates the growth rate of losses with the increasing distance d. The reference distance d_0 is determined by the measurements close to the transmitter. The parameter n depends on the specific propagation environment conditions, such as the type of building construction, architecture, and location of the point where the measurements are carried out. Where n = 2, we have a classic free-space path loss model; where n < 2 – we have the so-called waveguide effect (signal amplification); where n > 2 we have signal propagation under NLOS conditions or in the presence of other strong effects (e.g., diffraction, refraction, etc.).

Several authors proposed to modify the log-distance model so as to evaluate the impact of floors on signal propagation. For example, in the study [10], the following "damping factor" model is proposed

$$PL = PL(d_0) + 10n_{sf}\lg\left(\frac{d}{d_0}\right) + FAF , \tag{2}$$

where n_{sf} is the loss factor, and FAF is the floor-induced suppression factor, which depends on the number of floors between the transmitter and the receiver. Both the n_{sf} and the FAF are determined by experiments.

A similar model was proposed in [11]. This model includes an additional loss factor, which increases along with increasing distance. The modified expression of loss assessment is presented in (3)

$$PL = PL(d_0) + 20\lg\left(\frac{d}{d_0}\right) + \alpha d + FAF , \tag{3}$$

where α describes the attenuation factor in decibels for a given channel.

The third model introduced by Motley and Keenan [12] combines a few additional damping factors. The mathematical expression of this model is shown in (4)

$$PL = PL(d_0) + 10n\lg(d) + kF , \tag{4}$$

where k is the number of floors between the transmitter and the receiver, and F is the individual floor attenuation factor.

III. MEASUREMENTS PROCEDURE

Two wireless access routers were used as signal sources in the experiments: D-Link DIR300 and Trendnet TEW410 APB (MIMO technology). More detailed technical characteristics are available in the papers [1]–[3].

Spectrum analyzer Anritsu's Cell Master MT812A was used to measure the received signal levels.

The signal sources were attached in the 4th floor corridor of the five-storey building at 1.47 m above the floor. The signal level measurements were carried out by gradually increasing the distance between the signal source and the spectrum analyser, while the latter was moved along the corridor centreline. The measurements were carried out on the 2 – 5 floors of the building. The measurements were performed approximately every 1 m. The corridors partitions and the corridors schemes were identical (Fig. 1).

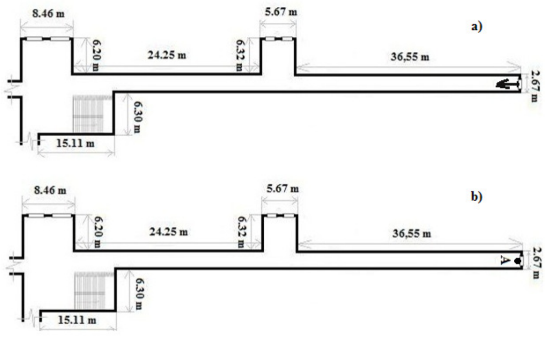

Fig. 1. a) 4th floor corridor plan. The arrow marks the location of the signal source and the receiver's direction of movement. b) the plan of the 2nd, 3rd and 5th floors. The letter A marks the point from which the measurements were carried out.

10 measurements were carried out at each point and each measurement was averaged after 10 seconds. The results of all the 10 measurements carried out at the single point were averaged and used for further analysis.

The experiments were carried out on the fifth, third and second floors of the building.

Measurement errors were estimated by the statistical methods described in papers [1]–[3].

IV. RESULTS

The measurement results are presented in Fig. 2 (D-Link) and Fig. 3 (TrendNet).

As it can be seen in Fig. 2 and Fig. 3, the floor number in respect of the transmitter has a substantial impact on signal propagation (one partition gives the damping of 10-12 dBm). In the 802.11g case, the signal disappears at 52 meters from the point A (Fig. 1.) on the second floor, and the breaking of the signal was recorded at the distance of 40-52 m.

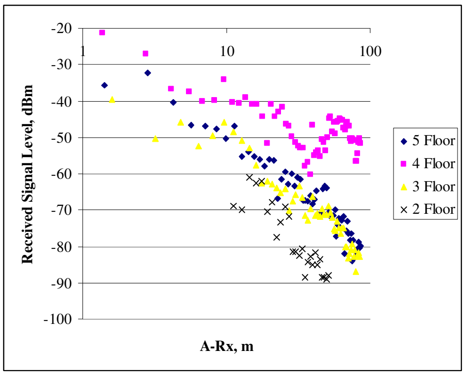

Fig.2. Impact of the floor on the signal strength (802.11g).

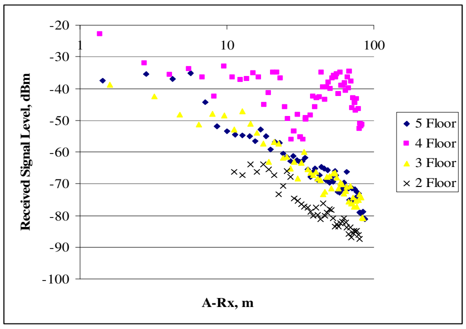

Fig. 3. Impact of the floor on the signal strength (802.11n).

In the 802.11n standard case, the signal remained stable and completely disappeared only on the second floor at 80 m from the point A. However, the signal started to break a little bit earlier. The first break was at 50 m, then the signal quality improved; however, from the 70 m the breaking began to rise from 70 m. The values of the damping constant n are given in Table I.

The measurement results on the fifth and third floors are very similar because the conditions were almost identical: the same distance from the transmitter, and both floors are separated from the transmitter only by one floor. There is a slight difference from the results obtained in the studies [4] and [5], where n varies depending on the floor (in respect of the transmitter location), where the measurements were carried out.

The correlation coefficients of signals were calculated for the 5 and 3 floors of the building. Theoretically, the received signal levels should be the same because the conditions, as mentioned above, were the same on both the 3 and 5 floors. Therefore, the correlation coefficient should be close to 1.

TABLE I. VALUE OF THE DAMPING CONSTANT N FOR BOTH SIGNAL SOURCES

Floor	n	
	802.11g	**802.11n**
5	2,9	2,7
4	1,6	1,3
3	2,9	2,7
2	3,8	3,4

The measurements showed that the correlation coefficient stands at 0.945 and 0.922 for the 802.11g and 802.11n standards respectively. This suggests that the correlation between the measurements is strong. This strong correlation also proves the correctness of the experiment methodology.

The results in Fig. 2 and Fig. 3 as well as in Table I show the advantages of the 802.11n standard, compared to the 802.11g standard. First of all, it was observed that in all cases the 802.11n factor n was lower than in the 802.11g case. This shows that the obstacles affected the 802.11n standard signal less than the 802.11g standard. It must also be emphasized that these results were achieved by the 802.11n standard transceiver with transmission power lower (11 dBm) than in the 802.11g case (16 dBm). It can be assumed that in case of the same radiant power, the n values would differ more strongly than in this experiment. Second, the scattering of the results is lower in the 802.11n case than in the 802.11g case, i.e. results can be predicted more accurately in the 802.11n case.

Using the Motley and Keenan model, the damping coefficient (F=15 for the 802.11g and F=12 for the 802.11n standards) of each partition was established for each floor, and by using (4) the results were calculated and compared with these experiments (Fig. 4 and Fig. 5).

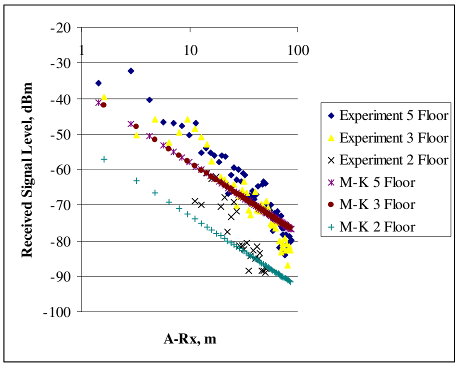

Fig. 4. Comparison of the Motley and Keenan model (M-K) and experimental data for the 802.11g standard.

It can be seen that the results of the Motley and Keenan model give a sufficiently large deviation from the experiments, especially at relatively small or very large distances from the point A.

This deviation at the distance of 15 m from the point A was between 13 % and 21.6 %, depending on the standard and the number of the floor in the building. Larger errors were observed where the signal source was the 802.11g standard wireless router.

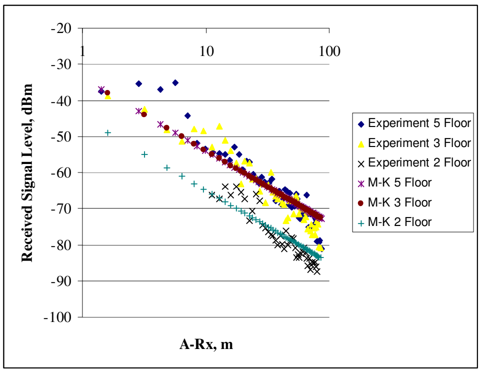

Fig. 5. Comparison of the Motley and Keenan model (M-K) and experimental data for the 802.11n standard.

The results of the Motley and Keenan model and the results of this experiment were practically the same and matched the tolerances at the distances larger than 15 m and smaller than 70 m from the point A.

As larger errors were obtained at the distances of 15 m and over 70 m from the start of the measurement, the model had to be revised. The following model is proposed

$$PL = PL(d_0) + 10\lg(d)\cdot(n+k), \qquad (5)$$

where k is the number of floors, and n is the damping coefficient under LOS conditions (Fig. 6 and Fig. 7).

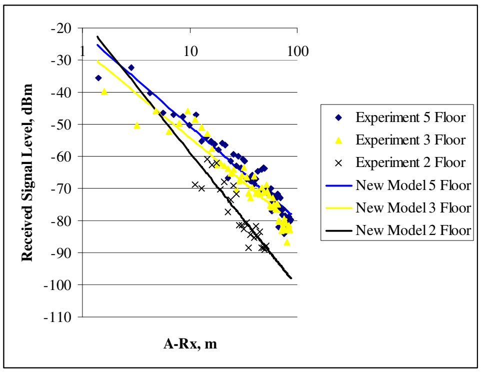

Fig. 6. Comparison of the new model (5) results and the results of the experiments for the 802.11g standard.

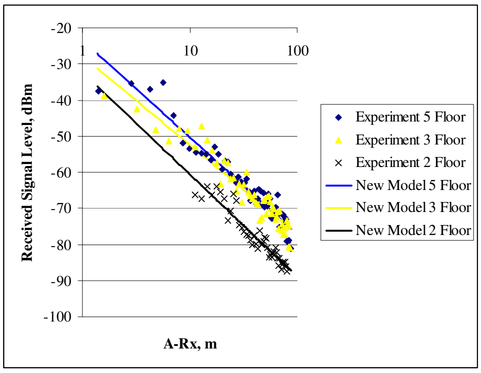

Fig. 7. Comparison of the new model (5) results and the results of the experiments for the 802.11n standard.

Having calculated the difference between the results of the revised model and the results of the experiment, the difference remained similar over the entire distance (86 m), i.e. it stood at 4.88 % on the 5th floor and at 1.95 % on the 2nd floor for the 802.11n standard; it stood at 4.65 % on the 5th floor and at 1.84 % on the 2nd floor for the 802.11g standard. Such errors in practice meet the experimental errors.

V. CONCLUSIONS

1. It has been found that there is a large discrepancy between the results of the Motley and Keenan model and the results of these experiments at the distances of up to 15 m and 70 m from the measurement point. Thus, it can be stated that the model performance is limited by distances;
2. A new model (5), which gives the resulting errors lower than 5 %, is proposed;
3. The results of the study can be used to improve or develop new radio wave propagation prediction models.

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