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The Research of IEEE 802.11 Signal LOS Propagation Features for Complex Geometry Indoors

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Abstract **– In this paper radio waves in the 2.44 GHz range LOS propagation in the long irregular form corridor have been researched. The D-Link and Trendnet wireless routers have been used as signal sources in the experiments. The experiments have been performed under the three scenarios. The results have been processed using some statistical methods and compared with the log-distance path loss model. Some amplification effects that require further investigations have been determined. The results can be useful for indoor radio wave propagation modeling and analysis.**

Keywords: **Indoor radio propagation, path loss, WLAN.**

I. INTRODUCTION

Wireless communication systems are one of the most rapidly developing telecommunications technologies at the moment. Their impact on daily life will continue to increase. Currently the one of the major challenges has become the convergence of the different technologies that allow a user to integrate the personal network with the global network and get an access to a wide range of services.

Especially high acceleration has resulted in the development of the Wireless Local Area Network (WLAN) technologies and their use in the indoor environment. This is particularly relevant to ensure the user's mobility and flexibility to use various services. To ensure the quality of those services it is necessary to pre-evaluate radio-wave propagation in indoor situations. Although a sufficient number of radio wave propagation prediction methods [1-8] have currently been offered, it is still difficult to predict how the radio frequency waves really act in the indoor environment even in the line-of-sight (LOS) conditions. Therefore, although a sufficient number of experiments are conducted, there is still a lack of experimental results carried out under various environments and building construction conditions which allow the accurate predicting of the data transmission of the WLAN networks.

The aim of this research is the experimental investigation of the 2.4 GHz band radio wave LOS propagation in the irregular geometry indoor environment according the 3 scenarios. Also in this paper there is an attempt to experimentally evaluate the different technological WLAN devices in accordance with the signal level in the receiver. Experimental results are compared with the two signal path loss methods.

II. RADIO WAVE LOSS IN INDOOR PROPAGATION

There are a sufficient number of experiments carried out in various indoor environments. Some of the works are associated with the signal strength measurement of relatively small rooms, some are carried out in the hallways or in the tunnels, and others are related to the radio wave propagation in the trains and airplanes. In the most works the experimental results are approximated by one or other model. The fact that indoor conditions are different makes the experimental results rather difficult to compare. Most experimenters have noted that the radio wave propagation in indoor LOS is similar to radio wave propagation in waveguides [2, 3, 4]. Some effects in the waveguides are studied in the [5, 6]. Therefore there is an attempt to interpret the results or existing radio wave propagation effects under the indoor (absorption, reflection, refraction, diffraction, scattering) or waveguide effects. However, in some cases the experimental results are difficult to explain according to the existing effects and describe according to the well-known models.

There are enough models for predicting radio wave propagation in indoor environment. One of the most popular models is the Log-Distance Path Loss Model which assumes that path loss varies exponentially with distance and is defined by the equation [1, 3]:

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

where $PL(d)$ is the path loss in the distance d, $PL(d_0)$ is the path loss in the distance d_0, d_0 is the close in reference distance in meters, n – is the path loss exponent.

Under that formula it can be determined what effect dominates in the indoor environment. If $n < 2$, the waveguide effect prevails.

III. MEASUREMENT SCENARIOS

The experiments were carried out in the fourth floor corridor of the building of the Faculty of Telecommunications and Electronics at Kaunas University of Technology (Fig.1). As it can be seen from the Fig.1, geometrical configuration of the corridor is very complex. There are a lot of bottlenecks and sudden broadening. Therefore, measurements should be made by increasing the distance between the transmitter and receiver step by step in small portions. It is the way for detecting effects that could cause this complex geometry of the corridor. The height of the corridor is 3.00 m, the length is 155 m. Other dimensions are shown in the Fig.2. The signal reflection and scattering effects from the surface of the restrictive corridors have a large impact on the measurements. These two effects as it is known strongly depend on the dielectric properties and signal frequency [9]. Reflective surfaces in the main corridor are a glass, wooden doors and plaster walls.

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Experiments were conducted at weekends so that the experimental results would not be influenced by people's movement and additional electromagnetic wave sources due to the operation of scientific and experimental hardware. Three scenarios were used when a wireless router was fixed at a height of 1.47 m and a receiver moved along the central axis of the corridor:

- Scenario 1 (Corridor). The measurements were carried out throughout the all length of the corridor. The distance between the router and the receiver was increased at intervals of 1 m to 90 m in length of the corridor and then increased every 5 meters;
- Scenario 2 (Corridor Back). In the both ends of the corridor over the wall there is the window which reflects the electromagnetic waves very well. In order to evaluate the influence of reflections signals along the corridor to the side of the window (back direction) were measured. Measurements were made every 1 meter;
- Scenario 3 (Hall). In order to assess the impact on the width of the room, the signals were measured along the hall in which one wall is the window, namely structurally it is similar to the corridors.

Two wireless routers were used as the original signal sources: D-Link DIR300 version 2.01 and Trendnet TEW410 APB that support the IEEE 802.11g (54Mbps) standard. The DIR300 works with one antenna and TEW410 works with two antennas (MIMO technology).

The receiver IC –R20 was used. The receiver was lifted to a height of 1.47 meters and was moving along the axial line of the corridor or hall.

IV. Measurement Results and Analysis

Scenario 1. The Fig. 2 and Fig.3 show the measurement data for all three scenarios where such wireless routers as D-Link and Trendnet are the access points (AP).

The results are compared with the free-space model (FSL) results. There is clearly seen that for the Tx-Rx distances higher than 52 m path loss is less than for the FSL for both D-Link and Trendnet.

Qualitatively similar dependence but not so strong is also obtained in the works [7, 8, 10]. This can be explained by waveguide effects which are minimized by multi-path effects. The fact that the corridor acts as a waveguide demonstrates the fact that, according to the formula (1), the best approximation of the results is achieved with $n < 2$ for the D-Link and Trendnet.

Strong maxima are clearly visible at about 60 m from Tx. The difference between the maximum value of the path loss at the distance Tx-Rx is about 37 m, and a minimum path loss of value at distance Tx-Rx is about 60 m, in D-Link case it is about 25 dBm, and for the Trendnet case the difference for the same distances is about 12 dBm. If compared with the loss in free space it can be seen that at the distance Tx-Rx of approximately 60 m the difference is about 15 dBm for the D-Link, and for the Trendnet case the difference is about 8 dBm.

Fig. 1. Corridor Plan. The basis of arrows shows the wireless router fixed position; the direction of the arrow shows the receiver moving direction.

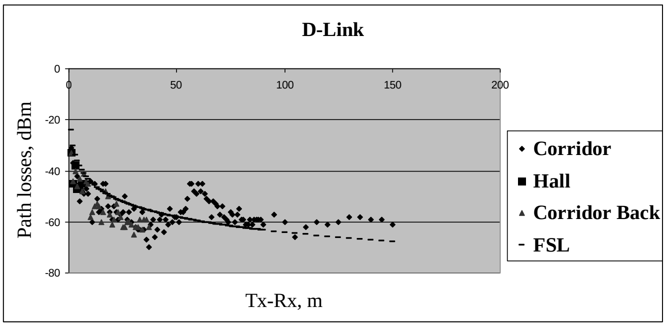

Fig. 2. Path loss vs. Tx and Rx separation for D-Link.

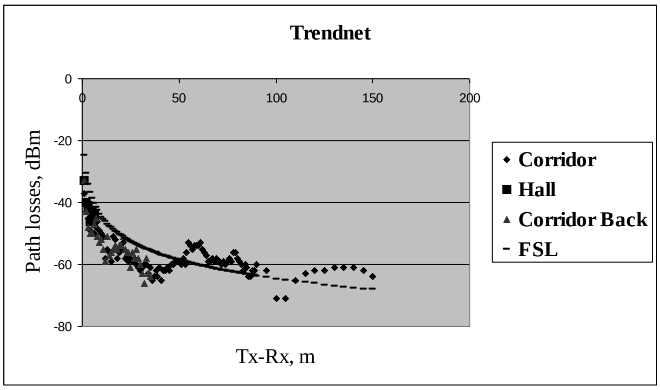

Fig. 3. Path loss vs. Tx and Rx separation for Trendnet.

Scenario 2. In order to evaluate the influence of the window (which has a large reflection coefficient compared to the plastered brick wall or wooden doors) on the measurements results, experiments according to the scenario 2 were carried out when the transmitter was placed in the middle corridor far enough away from the window and the receiver was moving in the direction to the window.

The results for D-Link and Trendnet are shown in the Fig.4 and Fig.5. The results of the scenario 2 are compared with the results of the scenario 1 at the same distance.

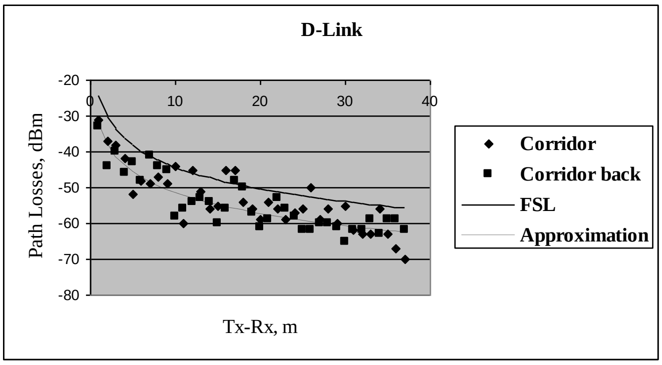

Fig. 4. Path loss vs. Tx and Rx separation for D-Link under the scenario 2.

It is seen that the window influence is not very significant. This influence is stronger at the short distance from the window (up to 1 m), and in case of D-Link higher loss is observed. The similar results for other surfaces with a good reflection coefficient are obtained in [11, 12]. For the Trendnet's case this influence is not significant. For the closer examination of the measurement data it can be seen that in case of D-Link when Rx approaches the window, the data scatter slightly decreases, while in case of Trendnet the data scatter is more or less the same. All of these moments as well as the above-mentioned ones can be explained taking into consideration the characteristics and specifics of MIMO technology.

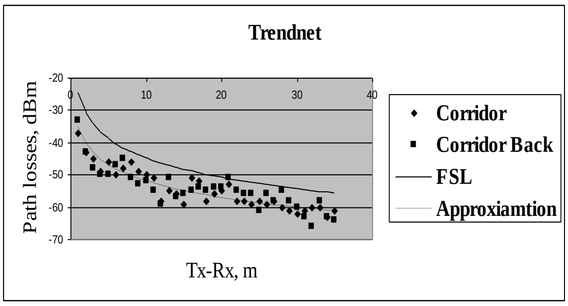

Fig. 5. Path loss vs. Tx and Rx separation for Trendnet under the scenario 2.

Comparing the results with the loss in the free space, it is obvious that the experimental data lies below the free space loss curve and this means that we have a traditional case. Some data of the D-Link lies above the free space loss data and indicates that the electromagnetic wave scattering effect on the signal level in the Rx is significant. Trendnet's case again shows that this effect is less marked.

The data for the scenarios 1 and 2 at the distance up to 37 m can be approximated according the formula (1) with $n = 1.9$ for D-Link and $n = 1.7$ for Trendnet. This shows that in both cases there is the waveguide effect but for Trendnet this effect is stronger.

Scenario 3. In this scenario an attempt was made to assess the indoor's geometry influence on the path loss. Indoor geometry is a rectangular. The transmitter was fixed in the middle of the window and the receiver was moving in the direction from the window. Measurements were made every 1 m at the distance up to 6 m from the window. The results were compared with the results of the Scenario 1 at the same distance.

The results are shown in the Fig. 6 and Fig.7 together with the path loss date in the free space.

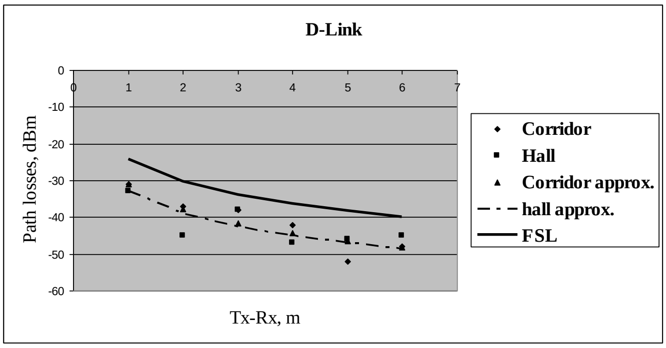

Fig. 6. Path losses vs. Tx and Rx separation for D-Link under the Scenario 3.

A comparison of the D-Link and Trendnet data again clearly shows that the scattering in the Trendnet's data is less than in the D-Link case. It may again be explained by the fact that the Trendnet uses MIMO technology.

By comparing the results of the hall and the corridor, it is clear that in the hall the scattering of the results is larger than in the corridor in both cases (D-Link and Trendnet). This can be explained by the fact that the window in the hall area is bigger than in the corridor, so the reflection of the electromagnetic waves can have stronger influence on the data.

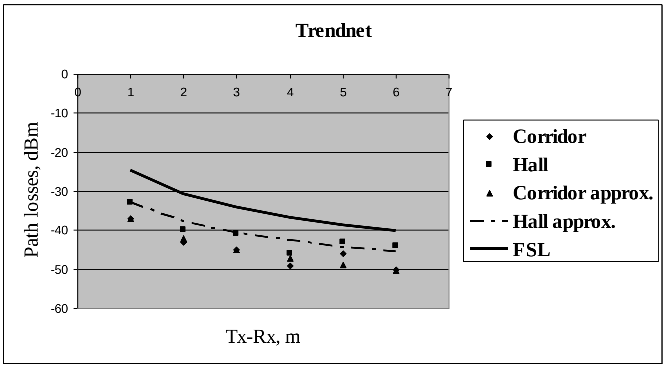

Fig. 7. Path loss vs. Tx and Rx separation for Trendnet under the Scenario 3.

According to the Fig. 6 and Fig. 7, some conclusions can be drawn about the indoor size influence on the path loss. In particular, there may be seen that the path loss in the hall is slightly smaller than in the hallway. Especially it can be seen clearly in the Trendnet case. In the case of D-Link, some data scatter could be seen, but the trend is the same as in the case of TRENDNET.

This can be explained by the fact that in the hall the effects of the electromagnetic wave reflections and scatterings are less than in the corridor. Data of the scenario 3 may be approximated according to the formula (1) with $n = 1.8$ for D-Link and $n = 1.6$ for Trendnet (Fig.8).

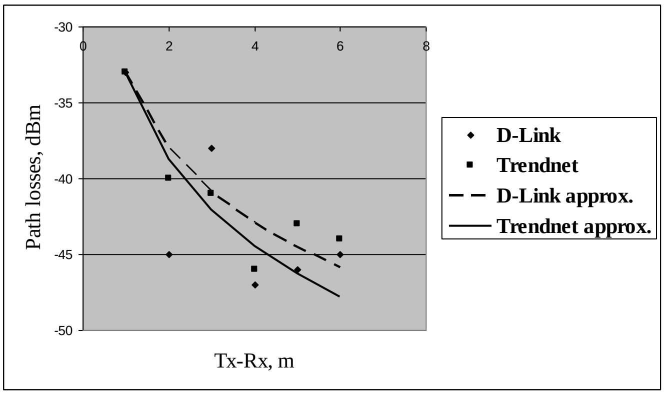

Fig. 8. Path loss vs. Tx and Rx separation for D-Link and Trendnet for the Scenario 3.

As it has been mentioned above, these results show that in both cases there is the waveguides effect but for Trendnet this effect is stronger.

At the same distance to the corridor the results show that the waveguide effect is less than in the hall. For D-Link case $n = 2.0$, and for the Trendnet case $n = 1.7$. Compared with the results of the entire corridor it can be seen that at the relatively small distances waveguide effect is less than at the large distances ($n < 1.75$ and < 1.0 respectively).

The results indicate that for the simple geometry corridor (the scenario 1 for the distances to 60 m and above 80 m and the scenario 2 and the scenario 3), results are similar as in the other works.

V. Conclusions

1. The results have showed that in the complex geometry corridor near the sharp changes in geometry of this corridor a clear and strong reduction in path loss has been observed which can be less than in case of free spaces loss. It does not depend on the technology used: normal or MIMO. This is a fact which requires further research, although this may partly be explained by a substantial influence of the diffraction, reflection and scattering effects;
2. The path loss reduction is observed more in the case of D-Link than in the case of Trendnet. This can be explained by the fact that Trendnet uses the MIMO technology which helps to compensate the reflection, scattering and some other effects. The data scattering is stronger in the case of D-Link than in the case of Trendnet and this can also be explained by the use of the MIMO technologies. This means that if the MIMO technology is used, the results and forecasting may be more accurate and more predictable;
3. It has been found out, that the corridor for the pass loss acts as the waveguide; it means that in the corridor the waveguide effect has been observed when n (formula 1) is less than 2. It indicated how the waveguide effect depends on the equipment used and distances between the transmitter and receiver. In particular, the strongest waveguide effect is clearly seen at larger distances and in case of Trendnet. It has been noted that the increasing indoor size increases waveguide effect but such increase is not substantial.
4. The influence of the surface with the large reflection coefficient (glass) on the path loss is significant only at relatively short distances (approximately up to 3 m). By increasing the distance, this influence reduces essentially. In addition, for the equipment that uses MIMO technology this influence is less according to the reasons which are described in the 1st conclusion;
5. Experiment results can be used to improve models for WLAN data transmission forecasting in the indoor LOS environment.

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Saulius Japertas, Agne Vencloviene. Standarta IEEE 802.11 tiešredzamības signālu izplatīšanās izpēte kompleksas ģeometrijas iekštelpās
Darbā tiek pētīti 2,44GHz radioviļņu izplatīšanās procesi tiešas redzamības zonā neregulāras formas garā koridorā. Kā signālu avoti tika izmantoti bezvadu maršrutizātori *D-Link* un *Trednet*. Eksperimenti tika veikti pēc trīs scenārijiem: visā koridora garumā; mērījumi, kuri ļāva novērtēt virsmas (t.i., sienu) ietekmi, kurām ir augsta atstarošanas spēja; mērījumi, kas ļauj noteikt telpas izmērus. Rezultātu apstrādē tika izmantotas statistiskās metodes; tie tika salīdzināti arī ar log-distances modeļa zudumiem. Iegūtie rezultāti parādīja, ka sarežģītas ģeometrijas koridorā nepārprotami un izteikti tika novērota izplatīšanās zudumu samazināšanās, kuri pie tam var būt mazāki nekā analogi zudumi brīvā telpā. Izplatīšanās zudumu samazināšanās vairāk ir novērojama D-linkos nekā Trendnet (ko var izskaidrot ar pēdējā lietoto MIMO tehnoloģiju). Tika novēroti daži signāla pastiprināšanas efekti, kuriem nepieciešami papildus pētījumi. Tika konstatēts, ka viļņiem izplatoties koridorā, var novērot viļņvada efektu, kas izteiktāk sevi uzrāda lielākos attālumos, kad ir izmantotas MIMO tehnoloģijas. Mērījumi parāda, ka augstas atstarošanas virsmas ietekmē dotās frekvences radioviļņus relatīvi nelielos attālumos (salīdzinot ar koridora garumu) attiecībā pret minētajām virsmām. Tika novērotas arī vairākas kvantitatīvas un kvalitatīvas radioviļņu izplatīšanās īpatnības atkarībā no konkrētām izmantotām MIMO tehnoloģijām. Rezultātus var izmantot radioviļņu iekštelpu izplatīšanās procesa modelēšanai un analīzei.

Саулюс Япертас, Агне Венцловене. Исследование распространения сигналов стандарта IEEE 802.11 в прямой видимости (LOS) в помещениях со сложной геометрией.
В работе исследуется распространение 2,44 ГГц радиоволн в зоне прямой видимости (LOS) в длинном коридоре неправильной формы. Как источник сигналов были использованы беспроводные маршрутизаторы D-Link и Trendnet. Эксперименты проводились по трем сценариям: по всей длине коридора; измерения, позволяющие оценить влияние поверхностей с высоким коэффициентом отражения (т.е. стекол); измерения, позволяющие оценить влияние размера помещений. Результаты были обработаны с использованием некоторых статистических методов и были сопоставлены с лог-дистанционной моделью потерь. Полученные результаты показали, что в коридоре сложной геометрии наблюдалось ясное и строгое уменьшение потерь распространения, которые могут быть меньше потерь в пустой среде. Были установлены некоторые эффекты усиления сигнала, которые требуют дальнейшего исследования. Было установленно, что в коридоре, при распространении радиоволн данной частоты имеет место волноводый эффект, который более сильно проявляется на больших расстояниях и при использовании технологии MIMO. Измерения показали, что поверхность с высоким коэффициентом отражения влияет на распространение радиоволны данной частоты на сравнительно коротких расстояниях (по сравнению с длиной корридора) от этой поверхности. Наблюдались некоторые качественные и количественные особенности распространения радиоволн в зависимости от использования или нет технологии MIMO. Результаты могут быть использованы для моделирования и анализа распространения радиоволн внутри помещений.