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Guide for Precise Path Loss Estimation in Indoor Environments

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Abstract

Providing coverage in closed environments becomes very crucial more and more. This is due to the great importance it gains nowadays as many indoor environments, such as factories, airports, large malls, and even indoor theme parks are deployed throughout the world. Internal base transceiver stations (BTSs) can be deployed to do so. Using internal BTSs can ensure permanent access albeit from inside buildings. In this paper, the author aims to reach a precise path loss estimation in closed environments (Indoor environments). This would significantly help the operators and cellular network designers due to the important role it is expected to play in determining appropriate cell size; that is a cell size with acceptable performance, which leads to achieve reasonable overall system cost. Matlab was used to realize the aforementioned goal. The path loss has been estimated in many possible indoor scenarios, which facilitates selection of appropriate cell size. The cell size may vary according to the required signal-to-noise ratio (SNRreq).

Keywords: wireless channel characteristics, attenuation and dispersion, large-scale fading, small-scale fading, path loss predicting models.

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دليل لتقدير دقيق لخسارة المسار في البيئات الداخلية

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الملخص

أصبح توفير التغطية في البيئات المغلقة أمرًا بالغ الأهمية أكثر فأكثر. ويرجع ذلك إلى الأهمية الكبيرة التي تكتسبها في الوقت الحاضر حيث تنتشر العديد من البيئات الداخلية، مثل المصانع والمطارات ومراكز التسوق الكبيرة، وحتى المتنزهات الداخلية في جميع أنحاء العالم. للقيام بذلك، يمكن نشر محطات الإرسال والاستقبال الأساسية الداخلية (BTSs). يمكن أن يؤدي استخدام BTSs الداخلية إلى ضمان الوصول الدائم ولو من داخل المباني. يهدف المؤلف في هذا البحث إلى الوصول إلى تقدير دقيق لخسارة المسار في البيئات المغلقة (البيئات الداخلية). وهذا من شأنه أن يساعد بشكل كبير مشغلي ومصممي الشبكات الخلوية بسبب الدور الهام الذي من المتوقع أن يلعبه في تحديد حجم الخلية المناسب؛ وهو حجم خلية ذو أداء مقبول، مما يؤدي إلى تحقيق تكلفة إجمالية معقولة للنظام. تم استخدام ماتلاب لتحقيق الهدف المذكور أعلاه. وقد تم تقدير خسائر المسار في العديد من السيناريوهات الداخلية المحتملة، مما يسهل اختيار حجم الخلية المناسب. قد يختلف حجم الخلية وفقًا لنسبة الإشارة إلى الضوضاء المطلوبة (SNRreq).

الكلمات المفتاحية: خصائص القناة اللاسلكية، التوهين والتشتت، الخبو واسع النطاق، الخبو صغير النطاق، نماذج التنبؤ بخسارة المسار.

1. Introduction

Losses in transmission channels arise because of many phenomena including reflection, diffraction, and scattering. Measuring the path losses in transmission channels in cellular systems is extremely important because of its role in determining the cell area, as measuring the wrong losses may result in poor system performance on the one hand, and on the other hand, may result in an increase in the cost. The importance of this type of communication system increases in some countries that are characterized by its extremely hot, rainy, and even very cold climates. It is expected that the pace of demand for this type of communications system will increase with the changes in climate that the world is witnessing recently.

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These changes may result in a significant increase in temperatures, and a sharp decrease in temperatures, and may also result in an abundance of rainfall in the other parts of the world. In this paper, the author aims to reach a precise path loss estimation considering Indoor environments. This would effectively contribute in assisting operators and cellular network designers due to the important role it is expected to play in determining appropriate cell size, which in turn leads to achieving reasonable overall system cost. Matlab was used to realize the aforementioned goal.

2- Effect of correct and incorrect path loss calculations

The incorrect calculation of losses may lead to designing cells with smaller areas than they are assumed to be which in turn, leads to an increase in the cost. For example, suppose we have an area of 40 km x 40 km (1600 km^2), then we need 400 cells if the calculations show that the required cell area is 4 km^2. If the calculation of the cell area was incorrect and the appropriate area is 8 km^2, then the actual number of cells that we really need is 200 cells, which confirms that there is a twice increase in cost. Figure 1 explains what will happen when relying on correct or incorrect path losses calculations.

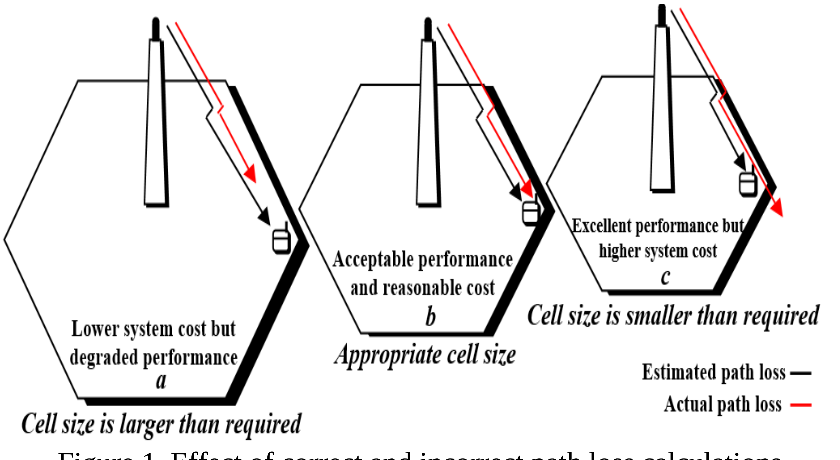

Figure 1. Effect of correct and incorrect path loss calculations

Several models that aim to realize precise path loss prediction were introduced in the literature [1-6] [7]. They started with the basic and simplest free space (FS) prediction model. Later, the FS model was followed by several prediction models. Figure 2 shows reviews of some famous path-loss predicting models.

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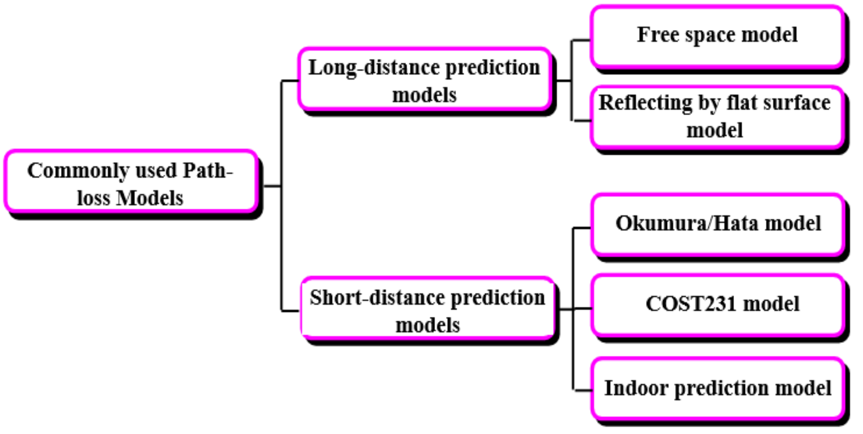

Figure 2. Commonly used path loss prediction models

Cellular communications systems can provide coverage in closed areas (indoor environments) by using internal BTSs. Providing indoor coverage is crucial as it ensures users to stay connected albeit from inside buildings. Examples of indoor environments include factories, airports, large malls, and even indoor theme parks.

3- Literature review

Many related works can be found in the literature. For example, Zaarour et all in [8] aimed to predict the path loss exponent (PLE) by exploiting the sensor connectivity measurements within a prescribed zone. Another method was used to achieve the same goal in [8] which is predicting the PLE. The method was based on use of a Received Signal Strength Indicator (RSSI). By using the termed log-distance path loss model, the method was able to minimize errors in the distance estimation process [9]. Researchers in [10] combined the two approaches used in [8] and [9] to determine the locations of wireless devices using 2D indoor environment. Although the method shows 7.42 % of deviation compared to methods that based on measurement approaches, it is assumed to be successful as 7.42 % lies in the acceptable deviation range. Researchers in [11] analyzed the performance of the distributed estimation-based wireless sensor networks by developing a framework that is based on a homogenous Poisson point process. The analysis used various scenarios of fading between sensors and the Fusion Center (FC). Researchers in [12] estimated the human body shadowing loss using the termed double-isolated-knife-edge diffraction (DIKED) model. These results confirmed that human body parts, such as arms, hair, and even clothing can cause a

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significant impact at 300 GHz. Researchers in [13] proposed a theoretical model to estimate path loss in citrus plantations (CS) at frequencies 1800 and 2100 MHz. The results show that satisfactory path loss measurements can be achieved based on reflection from soil within 10 m. However, for ranges beyond 10 m, reflection from trees also becomes necessary to obtain an accurate estimate.

4- Theoretical background

To provide coverage in closed environments becomes very crucial. This is due to the great importance it gains nowadays as many indoor environments such as factories, airports, large malls, and even indoor theme parks are deployed throughout the world. To do so, internal BTSs can be deployed. Using internal BTSs can ensure permanent access albeit from inside buildings.

The Indoor model is developed to precisely estimate the path loss within closed environments in which Pico-cells are deployed. Pico-cells are used when the distance does not exceed 100 m.

The indoor prediction model tells us that the path loss in dB cab be calculated using the following formula [14]:

$$L_{P[dB]} = \overline{L}_P(d_o) + 10\gamma Log d + L_f(n) + X_\sigma \tag{1}$$

Where $\overline{L}_P(d_o)$, γ, d, X_σ, and $L_f(n)$ represent the path-loss at the first meter in dB, path-loss exponent, separation distance meter, shadowing impact in dB, and attenuation via n floors in dB.

$\overline{L}_P(d_o)$, γ, X_σ, and $L_f(n)$ are listed in Table 1. These values are valid at 900 MHz and 1700 MHz [14] [15].

Table 1. Values of parameters at residual, office, and commercial indoor cases.

	Indoor cases		
	Residential	**Office**	**Commercial**
$\overline{L}_P(d_o)_{[dB]}$	38	38	38
γ	2.8	3	2.2
$L_f(n)_{[dB]}$	4n	15+4(n-1)	6+3(n-1)
$X_{\sigma[dB]}$	8	10	10

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5- Workflow

As we mentioned above, the main goal is to achieve an accurate calculation of path loss in indoor environments. This would lead to an ideal calculation of the cell area, which results in reaching a reasonable overall system cost. The work begins by calculating the expected loss in the path between the base station and the mobile station based on SNR_{req}.

SNR_{req} in decibel is given as:

$$SNR_{req} = Smin_{dBm} - N_{dBm} \tag{2}$$

Where:

$Smin_{dBm}$ representing receiver sensitivity, and N representing noise power at the receiver.

The expected path loss (LPINDOOR [dB] [the path loss in indoor environment]) can be calculated using the following formula which takes into consideration all the gains and losses the signal experiences till it reaches its destination [15]:

$$L_{PINDOOR[dB]} = Pt_{dBm} + Gb_{dB} + Gm_{dB} - L_o - Smin_{dB} \tag{3}$$

Where:

Pt dBm is the transmitted power, Gb dB and Gm dB are the base station and mobile station antenna gains, respectively. Lo is losses at the mobile device, sometimes referred to as system losses.

We then derive the path loss equation using the indoor model as in (1) and finally calculate the cell radius by taking (1) = (3).

6- Results and discussions

This part reviews graphically the three possible cases of indoor path loss scenarios which are the path loss within residential, office, and commercial indoor environments. This would facilitate the process of choosing the appropriate cell size and thus contribute to the speed of design. Figure 3 shows the relation between path loss and distance (distance between transmitter and receiver) considering the aforementioned scenarios. It can be obviously noticed from the graph that the path loss increases with the increase in the separation distance in all cases which is logical, however, the loss is much higher in the case of transmitting in the office environment. This is

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in fact would lead to use cells with smaller sizes compared with those cells used in the two other environments, and thus a greater number of cells.

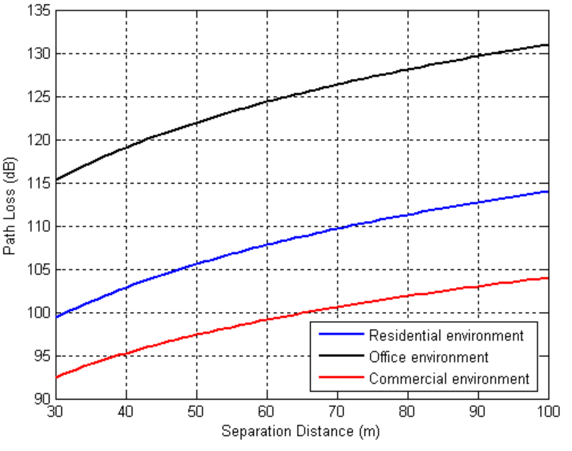

Figure 3. Path loss versus distance at residual, office, and commercial indoor environments

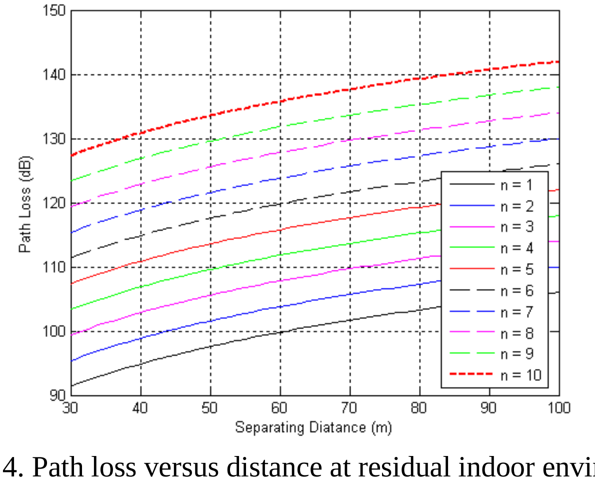

Figure 4. Path loss versus distance at residual indoor environment considering up to 10 levels

The building levels are also considered in this part (up to 10 levels). Figure 4 shows the path losses against distance at the residual indoor environment taking up to 10 levels into consideration. It is obviously seen from the graph that the path loss increases with the increase in the number of levels, that is the higher the building the greater the number of cells needed. Figures 5 and 6 show the path losses against distance at the office indoor environment and the commercial indoor

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environment considering up to 10 levels. Comparing these three figures, All the graphs follow the same behaviour, however, the one in which the office environment is considered shows the highest loss.

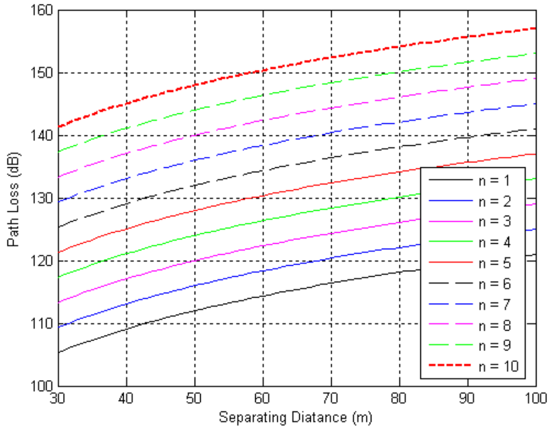

Figure 5. Path loss versus distance at office indoor environment, up to 10 levels are considered

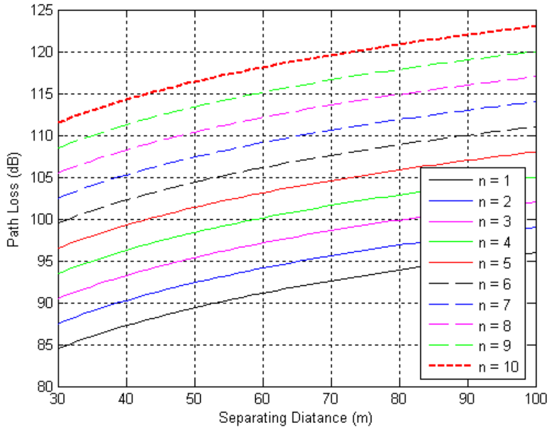

Figure 6. Path loss versus distance at the commercial indoor environment, up to 10 levels are considered

7- Conclusions

In this paper, indoor path loss has been precisely estimated using an indoor path loss prediction model. The path losses have been estimated considering three possible cases of Indoor environments. This would play an important role in determining appropriate cell size, which facilitates and speed up operators' work. The cell size

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can be increased by using high sensitivity receivers, which may further reduce the cost.

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