Indoor Propagation Modeling for Wireless Local Area Network (WLAN) [1]

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Abstract

This paper presents indoor propagation modeling for wireless local area network at 2.4GHz. Different propagation path loss models are simulated such as the International Telecommunication Union (ITU) and the log-distance path loss models. The ITU model is tested in residential or office environments, and is examined; wether the position of the Access Point (AP) and the WLAN cards on the same floor or in another floors. Log-distance path loss model is tested and simulated; from this model the effects of the shadowing deviation can be seen. Practical measurements will be taken by using a laptop equipped with the NETSTUMBLER 0.40 software to see the impression of walls and doors. Different charts are illustrated to view the responses of ITU and log-distance path loss models versus distances, path loss, transmitting power and receiving power. Practical data are also plotted in different cases, for open area between AP and mobile user and in a random positions case.

Keywords: *WLAN, Indoor Propagation Models, ITU and Log Distance Path Loss Models*

الخلاصة

عرض هذا البحث صوراً مختلفة لنمذجة الانتشار الداخلي للشبكات المحلية الداخلية اللاسلكية التي تعمل بتردد 2,4 جيجا هيرتز. و أجرينا عملية المحاكاة لنماذج الخسائر في مسارات الانتشار المختلفة مثل أنموذج الاتحاد الدولي للاتصالات (ITU) وأنموذج سجل المسافة (log-distance). و تم اختبار أنموذج (ITU) في البيئة المنزلية و المكتبية وفي حالات مختلفة، كأن يكون المرسل و المستقبل في نفس الطابق من البناية أو في طوابق مختلفة. وقد تمت دراسة أثار انحراف التظليل في الإشارة بعد اختبار أنموذج (log-distance). كذلك قمنا بأخذ قياسات عملية مختلفة باستخدام حاسوب محمول مزود ببرنامج (NETSTUMBLER 0.40) كمستلم لمشاهدة ودراسة تأثير الجدران والأبواب على الإشارة المستلمة. بعد الحصول على نتائج المحاكاة تم رسم المخططات البيانية المختلفة لدراسة الخسائر في الإرسالوالقدرة المستلمة والمرسلة نسبةً للمسافة بين المرسل و المستقبل، كما مثلت القياسات العملية في مخططات بيانية في حالتي وجود وعدم وجود عوائق بين المرسل و المستقبل.

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[2] Iraqi Commission for Computers & Informatics (ICCI)

1-Introduction

Today, wireless area networks WLANs based on the IEEE 802.11standard constitute a practical and interesting solution for network connection offering mobility, flexibility, low cost of deployment and use [1,2]. The number of people using wireless networks in an indoor environment is increasis very rapidly. Therefore, an efficient planning and developing for indoor communication is definitely essential. The indoor environment is considerably different from the typical outdoor environment and in many ways is more hostile. Modeling indoor propagation is complicated by the large variability in building layout and construction materials. In addition, the environment can change radically by the simple movement of people, closing of doors, and so on [3-6]. There are several causes of signal corruption in an indoor wireless channel; the primary causes are signal attenuation due to distance, penetration losses through walls or floors and multipath propagation. Signal attenuation over distance is observed when the mean receiving signal power is attenuated as a function of the distance from the transmitter. Thus, the received signal arrives as an unpredictable set of reflections or direct waves or both, each with its own degree of attenuation and delay.

The modeling of the propagation path needs to take into account a number of effects. These include the following [3-7]:

Path loss: The signal gets reduced in power with the distance it traverses following an inverse square law. So, ITU and log-distance path loss models are presented in this paper to understand the affecting parameters in the path loss for WLAN.

Shadowing: Scattering environments along various propagation paths will be different, causing variations with respect to the nominal value given by the path loss. Some paths will suffer increased loss; while others will be less obstructed and have increased signal strength. The log-distance path loss model is a modified power law with a log-normal variability, similar to log-normal shadowing. Some “typical” values from Ref [3,4] are given in Table 3. This phenomenon is called shadowing or slow fading and is said to follow log-normal fading statistics.

Multipath: These effects are caused by the local scattering environment around the access point (AP). Fig. (1) shows a representation of multiple signal paths in an indoor wireless implementation, where the signal lines intersecting are points of likely multipath reception problems and negative effects on wireless network signal integrity [8]. The solution of this problem is to get an access point closer to the users, or increasing the transmitted power.

This paper is organized as follows: Section 2 presents the ITU indoor path loss model and its expression. Log-distance path loss model is presented in Section 3. Section 4 presents calculations and measurement results for the following cases: single floor scenario based ITU model for both home and office conditions, multi floors scenario based ITU model, shadowing deviation effects scenario based log distance path model and finally the practical measurements. The last Section summarizes the paper and discusses the results.

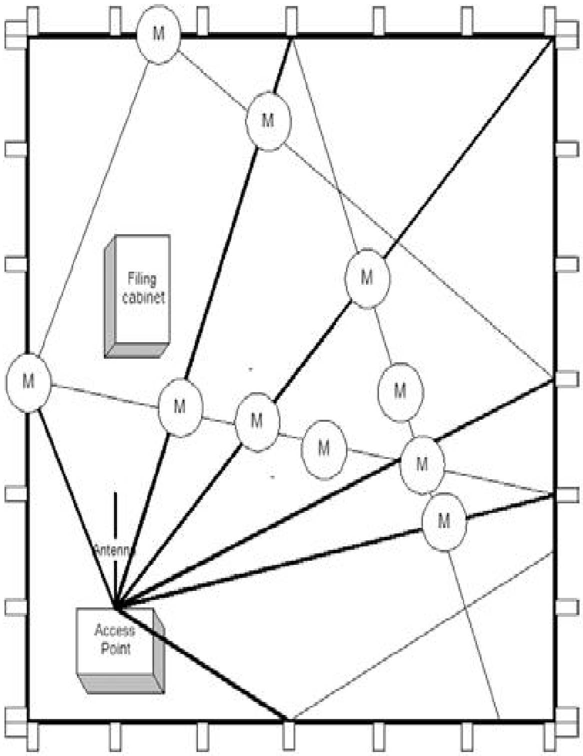

Figure (1) A representation of multiple signal paths in an indoor wireless network.

2-The ITU Indoor Path Loss Model

The indoor propagation path loss prediction for ITU model in dB is [4,5,9] :

$$L_{total} = 20Log(f) + NLog(d) + Lf(n) - 28 \quad (1)$$

Where, N is the distance power loss coefficient, f is the frequency of transmission in MHz, d is the distance in meter between AP and WLAN adapter card, L$f(n)$ is the floor penetration loss factor and n is the number of floors between the transmitter and the receiver.

The distance power loss coefficient, N is the quantity that expresses the loss of signal power with distance. This coefficient is an empirical one, some values are provided in Table 1. The floor penetration loss factor is an empirical constant dependent on the number of floors the waves need to penetrate; some values are tabulated in Table 2.

Table (1) Power Loss Coefficient Values, *N*, for the ITU Model

Frequency Band	Residential Area	Office Area	Commercial Area
900 MHz	N/A	33	20
1.2-1.3 GHz	N/A	32	22
1.8 – 2 GHz	28	30	22
4 GHz	N/A	28	22
5.2 GHz	N/A	31	N/A

Table (2) Floor Penetration Loss Factor, *Lf*(*n*), for the ITU Model

Frequency Band	No. of Floors	Residential Area	Office Area	Commercial Area
900 MHz	1	N/A	9	N/A
900 MHz	2	N/A	19	N/A
900 MHz	3	N/A	24	N/A
1.8 – 2.0 GHz	1-3	4n	15+4(*n*-1)	6 + 3(*n*-1)
5.2 GHz	1	N/A	16	N/A

3-Log-Distance Path Loss Model

The Log-Distance Path Loss model for indoor propagation path loss prediction in dB is [4,6,10] :

$$L_{total} = PL(do) + NLog(\frac{d}{do}) + X_S \quad (2)$$

Where, $PL(do)$ is the path loss at the reference distance in dB, , N is the path loss distance exponent, d is the path distance in meter , do is the reference distance 1m, Xs is a Gaussian random variable with zero mean and standard deviation of σ in dB.

The free-space loss is expressed as:

$$PL(do) = -20Log(\frac{\lambda}{4\pi do}) \quad (3)$$

The log-distance path loss model is a modified power law with a log-normal variability, similar to log-normal shadowing. Some empirical measurements of coefficients *N* and σ in dB have shown the following values for a number of indoor wave propagation cases from References [3,4,10] are given in Table3.

Table (3), Typical Log-Distance Path Model Parameter Measurements

Building Type	Frequency of Transmission	N	σ (dB)
Vacuum, infinite space		20	0
Retail store	914 MHz	22	8.7
Grocery store	914 MHz	18	5.2
Office with hard partition	1.5 GHz	30	7.0
Office with soft partition	900 MHz	24	9.6
Office with soft partition	1.9 GHz	26	14.1
Textile or chemical	1.3 GHz	20	3.0
Textile or chemical	4 GHz	21	7.0/ 9.7
Paper or cereals	1.3 GHz	18	6.0
Metalworking	1.3 GHz	16/ 33	5.8/ 6.8

4-Calculations and Measurements Results

4.1-Single Floor Scenario Based ITU Model

In this section, single floor scenario is simulated based on ITU model, it has been tried in an environment of residential area and office area by considering application of WLAN using IEEE 802.11b standard with AP transmission frequency of 2.4 GHz. Let $Lf(n) = 0$ on the same floor, by substituting these values in eq.(1), the path loss expression for these values is:

$$L_{total} = 39.6 + NLog(d) \qquad (4)$$

From the power loss coefficient values given in Table 1, for an office building the value of *N* is found to be 30 and 28 for home area. After simulation of Eq.(4), the response of path loss versus distance between the AP and WLAN cards can be obtained as shown in fig.(2). Consider the transmitted output power from AP is 1w or 30 dBm with 6 dBi antenna gain, so, the effective radiated power (EIRP) is 36dBm or 4w, neglecting the receiver antenna gain, the received power for these values is:

$$\text{Pr} = -3.6 - NLog(d) \quad \text{(dBm)} \qquad (5)$$

The response of ITU model for the received power vs. distance is characterized in fig. (3).

4.2-Multi Floors Scenario Based ITU Model

In multi floors scenario, the floor penetration loss factor is 15+4(*n*-1) as mentioned in Table 2, so the path loss expression for 2.4 GHz for multiple floor is:

$$L_{total} = 39.6 + NLog(d) + 15 + 4(n-1) \qquad (6)$$

A graph of the ITU model response shows the path loss for multi floors between AP and WLAN cards or users as illustrated in fig.(4) for office area environment, where N=30.

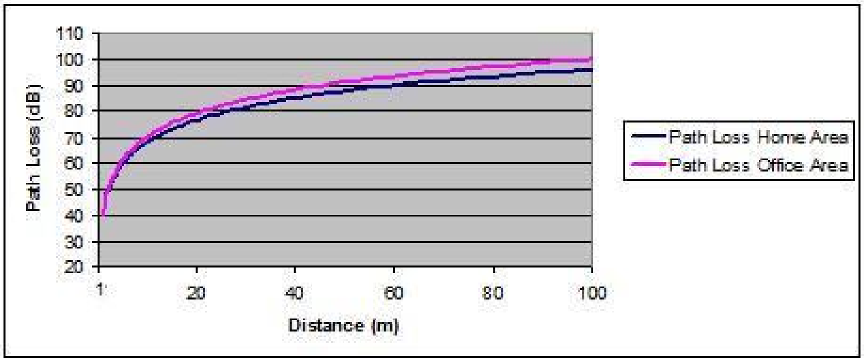

Figure (2) Response of the path loss for single floor scenario based ITU model for home area compared to office area.

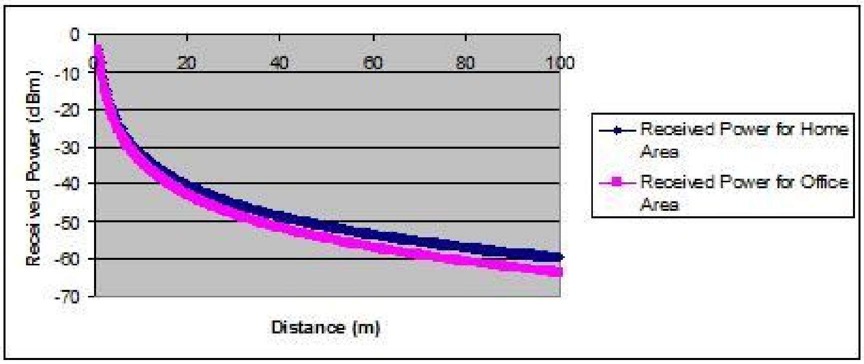

Figure (3) Response of the received power for single floor scenario based ITU model for home area compared to office area.

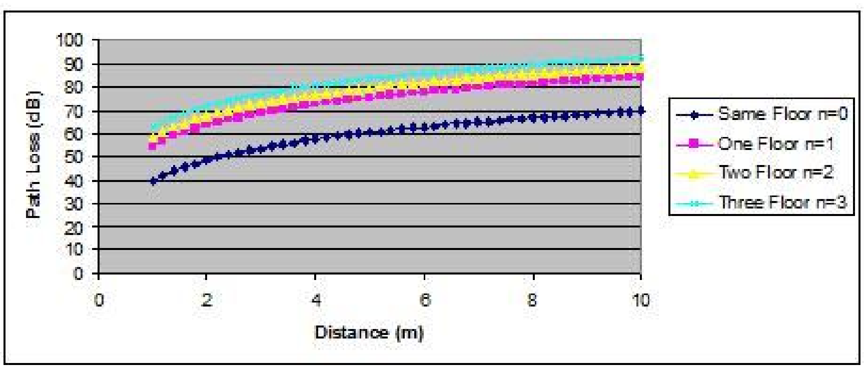

Figure (4) Response of the path loss in multiple floors scenario based ITU model for office area.

4.3-Shadowing Deviation Effects Scenario Based Log Distance Path Model

To study the modeling of wireless indoor propagation, it is important to use log-distance path loss model where the shadowing deviation comes into play as a significant parameter [6]. The mathematical expression of this model is given in eq. (2).

From eq. (3) the free space loss $PL(do)$ for 2.4GHz system is 40 dB, so the eq. (2) become as:

$$L_{total} = 40 + NLog(d) + X_S \tag{7}$$

For our simulation, the appropriate power decay index was assumed to be 30 [6]. The standard deviation σ was assigned of value 7 dB.

The standard normal pdf has a mean of zero and a standard deviation of unity. Any Gaussian random variable can be converted to an equivalent standard normal random variable using the transformation [4]:

$$z = \frac{X_S}{\sigma} \tag{8}$$

So, the probability of exceeding any particular value can be looked up in Table A.1 in Ref. [4] for complementary error function:

$$Q(z) = \int_z^{\infty} \frac{1}{\sqrt{2\pi}} \exp(-\frac{u^2}{2}) du \tag{9}$$

Consider that the coverage area is %90 so from the Q function table (Table A.1) [4], p = 0.1 occurs when $z \cong 1.286$. By using eq.(8), Xs is 9 dB.

Now, eq.(7) becomes :

$$L_{total} = 49 + 30Log(d) \tag{10}$$

The expression of received power in dBm is represented in eq.(11), by assuming (EIRP) 36 dBm and neglecting receiving antenna gain.

$$\Pr = -13 - 30Log(d) \tag{11}$$

Fig. (5) Shows the response of the path loss versus path distance for log distance model. Where the received power in the WLAN cards or users for log-distance model is shown in Fig.(6).

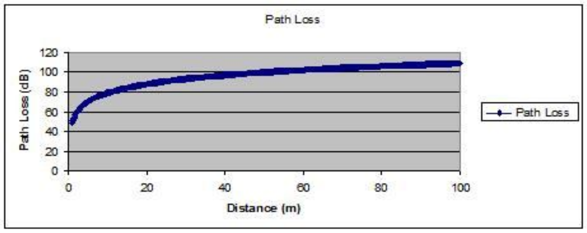

Figure (5) Response of the path loss for the log-distance model.

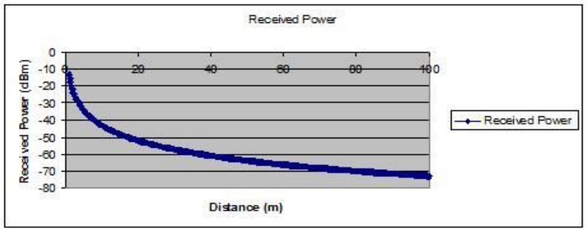

Fig. (6) Response of the received power for the log-distance model.

4.4-Practical Measurements

A laptop equipped with the NETSTUMBLER 0.40 software was used as the receiver detector, operated by a moving user [6,8]. The NETSTUMBLER software calculates the instantaneous signal strength based on a ray-tracing incorporated technique of arriving signal components as shown in fig. (7). In technical terms, different measurement locations were recorded with 30 dBm transmitting power. Fig (8) shows a practical graph for different distances for open area between AP and the laptop inside the building. Fig (9) shows a practical graph but the measurements were taken in different locations randomly through the walls to examine the building layout and understand the obstacles to propagation that are present. This experiment was done in home area which the approximately sketch as shown in fig.(10) with typical dimensions about 200 m^2.

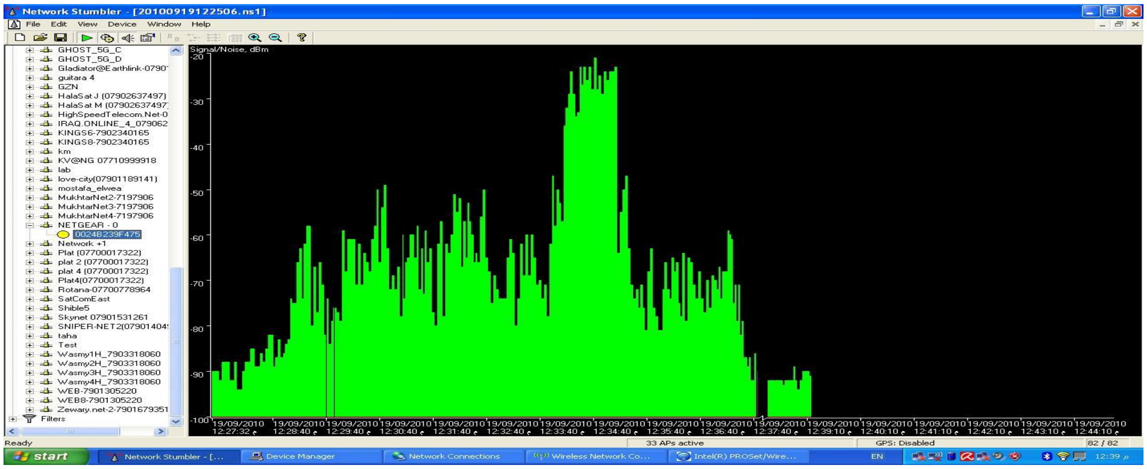

Figure (7) The NETSTUMBLER 0.40 program.

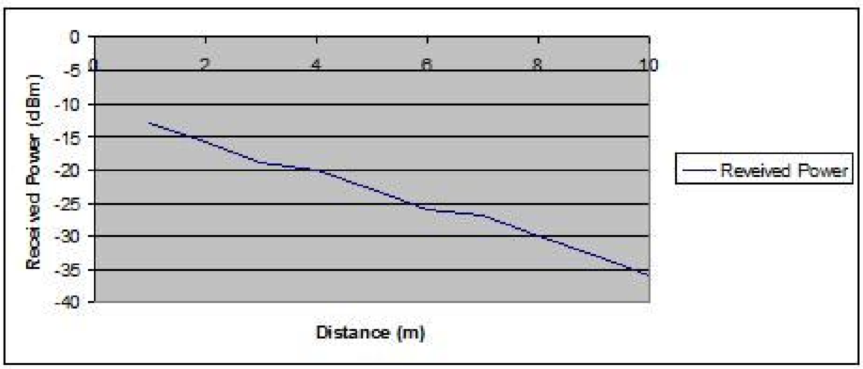

Figure (8) Response of the received power for open area between AP and the laptop.

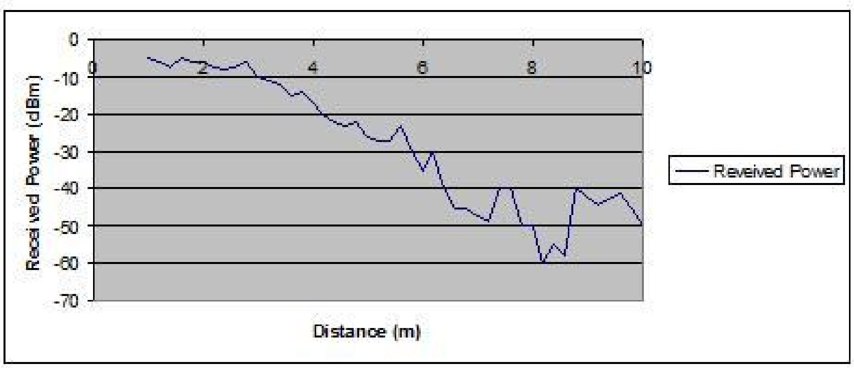

Figure (9) Response of the received power for randomly locations between AP and the laptop.

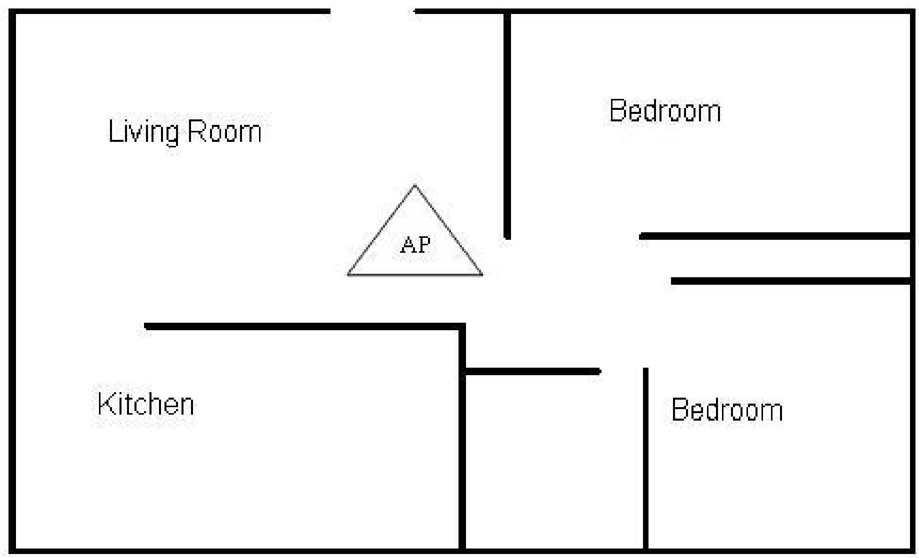

Figure (10) A typical home layout.

5. Conclusions

The indoor propagation modeling for WLAN was addressed in this paper. Different cases and models were simulated and technical requirements were also taken in consideration . The simulations of ITU model shows the response of the path loss via the distance between the AP and the mobile users and it was tried in the same floor and in multi floors system as illustrated in fig. (4), from this figure we can deduce that it is better to have the AP site in the same floor with the users to avoid the extra path loss. The ITU model was tested in residential area and also in office area which is more complicated by the frequent movement of people and the quantity of partitions as shown in fig.(2). There is a little difference of path loss in small distances and it increases with respect to distances, Fig.(3) verifies the received power (d Bm) at the user site versus distances by considering EIRP 36 dBm and ignoring receiver antenna gain. Log distance path loss model had been tested and simulated. It is important when studying indoor propagation modeling to highlight the log distance, because this model notifies the shadowing deviation effects. The response of log distance model were plotted as in fig.(5) and fig.(6), by considering %90 coverage. Practical measurements were taken in different positions and distances in house area using 802.11b standard wireless network. In this work, the is used AP as transmitter with EIRP 36dBm and using a laptop equipped with the NETSTUMBLER software as a receiver. The tested results were illustrated as shown in fig. (8) for open area between transmitter and receiver and in fig.(9) for random positions between AP and laptop. From these results there is a little drift between practical and calculated results. It is important to model the indoor environments which are useful in designing WLAN to study the coverage area of AP and also to select the transmitting power, transmitting antenna gain,and receiver antenna gain but in the range of Federal Communications Commission (FCC) conditions [8]. Wireless networking is perfect for home and office networking but one of the most common problems is to select the optimum location for AP to allowed either desktop PC or laptop to connect to the wireless network. If the building area is more than $200m^2$ it is better to use more than one AP and it is optimum to put access points in the center location of the floor. Finally the empirical models presented in this work are not limited to 802.11b standards, but could be used for 802.11g with transmitting frequency of about 5.2 GHz.

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