Loss Correction of Wireless Model in Complex Multi Wall Environment

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Abstract. K-M (Keenan motley) model calculates the total loss value of indoor wireless signal penetrating multiple walls by adding fixed loss values of single wall, without considering the influence of wireless signal polarization and incident angle on wall loss. In order to solve this problem, considering the polarization and incidence angle of the beam, the wall and its direction can be detected automatically from the blueprint image by Hough transform in image processing. By obtaining the direction and angle of the wall, the loss attenuation is defined as a function of the incident angle. The improved model can define various types of walls with different attenuation characteristics. Through the comparison of actual measurement, the error between the improved model and the measured road strength loss is reduced, and the root mean square error between the measured value and the prediction value of the improved model is obviously improved, and the prediction accuracy of the model in indoor environment is improved.

Keywords: Propagation model, Multi wall environment, Incident angle, Pass loss

1. Introduction
Wireless systems are an important part of our daily life. Because of their accessibility、flexibility、cost-effectiveness and mobility, they have been integrated into residential, commercial and even industrial environments. In order to accurately predict the radio wave coverage in any environment, it is very important for network providers to understand the characteristics of signal transmission and provide effective and cost-effective wireless local area network (WLAN).

The Keenan motley (K-M) model is introduced in references [1-2]. This model is commonly used in the laboratory, and one of the most concerned models among many models. Lima et al. Also adjusted the K-M model and improved the accuracy by adding an additional term to explain the wall thickness to the model [3]. The model was modified to solve the nonlinear relationship between the cumulative seepage loss and the number of walls [4].

2. Indoor propagation model
In modern indoor buildings, the loss of wireless transmission is greater than that of free space transmission, and the attenuation of signal through the wall is greater than that in each room. For
commonly used indoor models, such as attenuation factor model and ITU-R 1238 model, the signal attenuation is evenly distributed to each wall through road loss coefficient, and the total loss value is finally obtained. When the signal environment becomes complex, it is impossible to make effective signal prediction.

On the contrary, K-M model divides the total propagation loss into three parts: indoor free space propagation loss, wall attenuation and floor attenuation. The formula of the model is shown in (1).

\[
PL(d) = PL(d_0) + 10\log \left(\frac{d}{d_0}\right) + \sum N W_i + \sum K F_j
\]  

Among them: \(PL(d)\) is the received power at \(d\) m away from the transmitter, \(PL(d_0)\) is the received power at 1m from the reference distance, \(N, K\) is the number of walls and floors, \(W, F\) is the loss factor of corresponding wall material and floor material, and \(\alpha\) is attenuation coefficient factor.

According to the formula, the K-M model does not consider the angle between the signal and the wall when it is incident on the wall, and regardless of the angle between the normal vector between the wall and the wall, the through wall loss is defined as a fixed attenuation factor, and the attenuation is independent of the angle. In order to solve the influence of polarization and incident angle on walls of different materials, we use the effective dielectric constant in reference [5], which solves the constant factor \(\alpha\) assigned to each obstacle or wall. On the contrary, the fixed dielectric constant \(\varepsilon_r\) is assigned to the wall in 3D ray tracing algorithm, and the transmission coefficient \(\Gamma\) of the penetrating beam is a function of the \(\theta_r\). When the signal penetrates the indoor wall, the two factors of \(\theta_r\) and polarization mode of radio wave are taken into account, and the \(\Gamma\) is calculated by Fresnel coefficient [6]. Although the dielectric constant of the wall is fixed, the transmission coefficient corresponding to different \(\theta_r\) and polarization modes is not a fixed value. In order to verify the influence of the introduced parameters on the K-M model, the influence of \(\theta_r\) on typical building materials is studied firstly. We can get the complex value of \(\varepsilon_r\) in the range of 0.01MHz to 10GHz [7], and list the real parts of different materials in Tab.1. In the case of TE polarization, the construction materials in the test environment are described, as shown in Fig.1.

The results show that the penetration loss of the wall increases with the increase of incident angle. For example, when the incident angle is from 50 to 80 degrees, 7 dB and 11 dB increase in TE polarization for wood and glass, respectively.

| Material    | Metal   | Wood   | Glass  | Brick |
|-------------|---------|--------|--------|-------|
| Relative permittivity | 1       | 1.99   | 6.27   | 3.75  |
| Test frequency (GHz)   | 1-100   | 0.001-100 | 0.001-100 | 1-10  |

**Tab.1 Relative permittivity of common building materials**

![Fig.1 Variation of TE polarization signal level with incident angle 0 to 90 degrees](image-url)

**Fig.1** Variation of TE polarization signal level with incident angle 0 to 90 degrees
3. Improvement of K-M mode

Combined with reference [8], the improved model formula is shown in (2).

\[
PL(d) = PL(d_0) + 10 \log_{10} \left( \frac{d}{d_0} \right) + \sum \Gamma(\theta_i)
\]  

(2)

The key to the application of this model is to find the incident angle between the signal and the wall. This process is easy to implement in 3D and 2D ray tracing models. The wall is defined by vector equation, but it is very complex and difficult to realize. For the modified model, the indoor plan drawn according to the measured scene, and then the structural blueprint drawn by the 1-pixel line proportional example can be completed. We can simply calculate the incident angle between the signal source and the interior wall. This processing method has three advantages:

1) 3D model is not needed.
2) There is no need to use vector equation to define the complex wall, which reduces the computational complexity of the model.
3) Improve the accuracy of propagation model.

Hough transform is used to determine and distinguish all indoor walls. Meanwhile, the direction \( \theta_N \) of the wall in the image can be determined in Hough space. The position of signal source (Tx) in the image is obtained interactively, and the angle seta between signal source and horizontal direction is calculated, and the relationship of three angles when the signal penetrates the wall is obtained: \( \theta_k = 90 - \theta_N + \phi \) [9], as shown in Fig. 2.

![Fig. 2 Derivation principle of \( \phi \) in blueprint image](image)

After each wall is detected, an 8-bit gray image of the blueprint is generated. Firstly, 255 is assigned to the signal source location on the specified image, and then each wall has different pixel strength from 254. In this way, different walls can be distinguished, and the signal strength can be connected with the specific dielectric constant \( \varepsilon_{\text{rx}} \) and direction \( \theta_N \). The Loss between Tx and Rx can be determined by the straight line Bresenham algorithm [10], and the pixel points intersecting the line of sight propagation in the gray image can be extracted. The algorithm is implemented by MATLAB. Starting from obtaining the blueprint, the blueprint image is calibrated by determining the length ratio between two pixels according to the actual thickness of the wall provided. Finally, the blueprint image is divided into a specific number of nodes, and the propagation loss of each pixel is calculated using the modified Keenan motley model, and the corresponding pixel level is assigned to each point. According to the other measurement information (transmission power 30dBm, antenna gain, transmission frequency, antenna height, etc.) set in the measured scene, and using the dielectric constant of TE polarization in reference [11], the propagation prediction simulation diagram of indoor scene is finally generated on the blueprint image through MATLAB. The results are shown in Fig. 3.
Fig. 3 Indoor signal strength prediction of improved model (1600MHz & 2400Mhz)

4. Indoor scene test and verification

4.1. Test and verification in indoor scene
First of all, the laboratory indoor test scene is accurately measured, mainly including drawing the layout of each room, walls, doors, etc. and then the indoor plan is drawn with CAD, as shown in Fig.4.

Fig. 4 Indoor test scene plan

4.2. Test plan and results
The indoor scene of the laboratory is selected for testing, and 40 test points with location characteristics are selected in the indoor. Before the test, the instrument and equipment are standardized. The Tx mark points in the figure are used as the signal source position, and the other 1 ~ 40 points are used as the receiving end. The test equipment mainly includes AV1464A synthetic sweep signal generator, Spectrum analyzer, Antenna height (156cm), etc. Omnidirectional antenna is used to transmit signal in the test, and the influence of vertical polarization mode on signal transmission is tested.

According to the characteristics of wireless signal propagation in the room, the following measures are taken in the test process:

1) During the test, the indoor doors and windows are closed, there is no person walking in the corridor and room, and there is no large electromagnetic interference in the indoor space. The test is repeated at 2400MHz and 1600MHz transmission frequencies in the same way.
2) The transmitter and receiver both use omni-directional antenna. Due to the large penetration loss of multiple walls in the room, the transmitting power is 30dBm (1W) to ensure that the received value of each test point is valid.

3) During the test, 40 times of each point are recorded, and the average value is taken as the signal receiving power of the point.

4.3. Scenario prediction analysis

By comparing the actual measurement with the modified model and the original Keenan motley model, the actual loss of 40 indoor receiving points is counted, as shown in Fig. 5. Compared with the original K-M model, considering the influence of the angle between the wireless signal and the wall and the polarization of the beam on the propagation path loss, the improved model successfully reduces the error between the predicted value and the measured data. Fig. 6 shows the distribution of error residual histogram at 1600MHz test frequency. It can be seen that compared with the original model, the improved model has more concentrated residual dispersion.

![Fig. 5 Path loss comparison of 40 test points](image)

![Fig. 6 Error residual histogram of K-M model and improved model with measured value(1600MHz)](image)

The calculation formula of root mean square error of error is as follows:

$$\sigma = \sqrt{\frac{1}{K} \sum_{1}^{K} (N_0 - N_p)^2}$$

In the formula, $K \cdot N_0 \cdot N_p$ is the number of experimental tests, the measured value of path loss and the predicted value. For the test results of the actual scene, Tab.2 provides the root mean square error (RMSE) and standard deviation ($\sigma$) of different models at two test frequencies.
The results show that the accuracy of the improved model is improved compared with the original model, and the error standard deviation and root mean square error of the improved model are significantly improved, which shows that the improved model can more truly reflect the radio wave propagation environment of indoor scenes compared with the original model, It can meet the needs of the environmental network planning.

5. Conclusion
The indoor path loss of wireless signal is mainly related to the signal strength and frequency. The higher the frequency, the higher the attenuation. For vertical polarization, the penetration loss will increase with the increase of incident angle. This paper only considers the indoor environment prediction of K-M model and improved model under two test frequencies. The actual measurement and result verification show that the prediction accuracy of the improved model is improved in the indoor multi wall scene. The indoor environment is very complex, there are various scenarios. Because the empirical model needs to obtain the general formula based on a large number of real house model tests, this paper only tests the path loss of radio waves on the multi wall of the same floor, so it is necessary to further study the penetration loss between floors and the impact of human body on electromagnetic wave transmission in each floor, The indoor wireless propagation prediction model with high accuracy and strong adaptability to complex scenarios is established.

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