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Channel Modeling for Mobile Terminals in Static Indoor Conditions

Teruya FUJII [1] Yoshichika OHTA [1]
[1] Laboratory, Soft Bank Telecom Corp.
2-38 Aomi Koto-ku, Tokyo, 135-0064 Japan
E-mail: teruya.fujii@tm.softbank.co.jp

1. Introduction

The number of customers who use cellular phones indoors is rapidly increasing. In this case, the mobile terminals are basically static and the communication characteristics are wildly different from those seen in outdoor moving use. On the other hand, indoor wireless access systems such as WLAN also become widely used. In static usage, the terminal itself doesn't move, but the environment around it change due to the movement of people, for example. In order to accurately evaluate the communication characteristics, a new propagation model (channel model) is necessary. However, few physical channel models have been for static indoor conditions [1].

In this paper, we propose a physical channel model for static terminals used in the indoor Non Line of Sight (NLOS) and Line of Sight (LOS) conditions. Analysis results of proposed model are compared against measured results and we show that the proposed model can well predict the measured results.

2. Proposed model

First we show the basic concept of the proposed model [2]. It sets up two environments. One is the surrounding static environment; it contains no moving object. The radio waves arrive at the terminal without being blocked by moving objects. The other is the surrounding moving environment; it contains only moving objects and only radio waves scattered by the moving objects arrive at the terminal. The proposed model combines the two environments in a direct manner.

Fig. 1 shows the proposed model. A moving object is assumed to block the radio waves and to perfectly absorb their power as shown in Fig.1. As the object moves, it blocks and absorbs other radio waves, so the received level at the terminal changes dynamically as shown in Fig. 2.

3. Analysis

3.1 Analysis model

Fig.3 shows the analysis model. Here we analyze as a two-dimensional model. The moving objects considered are only moving people; the i-th person is represented as a disk with diameter of w [m] separated from the terminal by r_i[m]. Each moving person walks in an arbitrary direction between 0 and 2π at a constant speed of v [m/s]. Each moving person moves within the annular area described by the circles, centered on the terminal, with radii of r_{min} and r_{max}. The number of moving person is N_{person} and a moving person absorbs perfectly the power of paths across his width of Δw. We assume the surrounding static environment as a lot of multipaths with the same power uniformly arriving from all horizontal directions and a direct path as shown in Fig. 4.

3.2 Received Level Analysis

Let the direct path's level and the i-th multipath's level at the terminal with position of x be $e_0(x)$ and $e_i(x)$, respectively. We assume that the number of multipaths is N_{path} and the path level absorbed by the k-th moving person is $\eta_k(t)$. The received level at the terminal, $E(t,x)$, can be presented as follows.

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$$E(t,x)=\begin{cases}\left(\left(e_0(x)+\sum_{i=1}^{N_{path}}e_i(x)\right)-\sum_{k=1}^{N_{person}}\eta_k(t)=\left(e_0(x)+\sum_{i=1}^{N_{path}}e_i(x)\right)-\sum_{k=1}^{N_{person}}\eta_k(t)\quad\text{(LOS)}\right.\\ \left(e_0(x)+\sum_{i=1}^{N_{path}}e_i(x)\right)-\left(\sum_{k=1}^{N_{person}}(e_0(x)+\eta_k(t))\right)=\sum_{i=1}^{N_{path}}e_i(x)-\sum_{k=1}^{N_{person}}\eta_k(t)\quad\text{(NLOS)}\end{cases}\tag{1}$$

Here $e_0(x)$ and $e_i(x)$ are given by

$$e_0(x)=A_0\exp\left[j\left(\frac{2\pi x}{\lambda}\cos(\theta_0)+\phi_0\right)\right]\tag{2}$$

$$e_i(x)=A\exp\left[j(\frac{2\pi x}{\lambda}\cos\left(\frac{2\pi(i-1)}{N_{path}}\right)+\phi_i)\right]\quad(i=1,---,N_{path})\tag{3}$$

where $A_{0.}$, θ_0 and ϕ_0 represent the amplitude, arriving angle and phase of the direct path, respectively, and A, $2\pi(i-1)/N_{path}$ and ϕ_i represent those of the i-th multipath, respectively. λ[m] is the wavelength. Assuming P_m is the total power of multipaths and each path has the same power, A can be given by $A=\sqrt{P_m/N_{path}}$. On the other hand, $\eta_k(t)$ can be presented by using the lowest angle $\theta_k^L(t)$ and the highest angle $\theta_k^U(t)$ of paths absorbed by the k-th moving person as follows.

$$\eta_k(t)=\sum_{i=\theta_k^L(t)}^{\theta_k^U(t)}e_i(x)\tag{4}$$

In Eqn. (1), NLOS and LOS represent the cases that the direct wave is cut off and not cut off, respectively. The first item of the right side of Eqn. (1) represents the level due to the surrounding static environment and its value doesn't depend on time t. On the other hand, the second item of the right side of Eqn. (1) represents the level due to the surrounding moving environment, which does depend on time t. When the number of absorption paths in Eqn. (1) is relatively large, the complex amplitude of absorption paths follows a complex Gaussian distribution due to the central limit theory. This is a noteworthy characteristic. From this characteristic, we find that Eqn. (1) can be presented as Nakagami-Rice distribution with factor K, which is defined as the ratio of direct path's power to the multipaths' power. Thus the received level characteristics can be expressed as the combination of two kinds of Nakagami-Rice distributions with different K factors. The received power distribution of Nakagami-Rice distribution is given by [3].

$$p(r_P,K)=(K+1)\exp[-(K+1)r_P-K]I_0(\sqrt{4(K+1)Kr_P})\tag{5}$$

where r_p is the received power and I_0(x) is the first kind 0th-order modified Bessel function.

We can obtain the received power distribution by calculating K factors and a ratio of the direct wave cut off. First, we calculate the K factors. Setting K factors of LOS and NLOS cases as K_{LOS} and K_{NLO}, respectively, K_{LOS} and K_{NLO} can be given by

$$K_{LOS}=|e_0(x)+e(x)|^2/\left|\sum_{k=1}^{N_{person}}\eta_k(t)\right|^2=|e_0(x)+e(x)|^2/|e_G(t)|^2\quad\text{(LOS)}\tag{6}$$

$$K_{NLOS}=|e(x)|^2/\left|\sum_{k=1}^{N_{person}}\eta_k(t)\right|^2=|e(x)|^2/|e_G(t)|^2\qquad\text{(NLOS)}\tag{7}$$

where $|e_G(t)|^2$ is the total power of the absorbed paths. When each moving person is at distance r_i, then $|e_G(t)|^2$ can be calculated as follows.

$$|e_G(t)|^2=\sum_{k=1}^{N_{person}}|\eta_k|^2=\sum_{k=1}^{N_{person}}P_m\Delta w/2\pi r_k\tag{8}$$

Assuming that the moving people are distributed uniformly in the moving area, $|e_G(t)|^2$ can be expressed as follows.

$$|e_G(t)|^2=\frac{N_{person}}{\pi(r_{max}{}^2-r_{min}{}^2)}\int_{r_{min}}^{r_{max}}\frac{P_m\Delta w}{2\pi r}2\pi r dr=\frac{N_{person}P_m\Delta w}{\pi(r_{max}+r_{min})}\tag{9}$$

Next we calculate the ratio of the direct wave cut off. Let the probability of a moving person cutting off the direct wave be q_{NLOS}. q_{NLOS} can be expressed as the probability that the center of the moving person falls within a rectangle with width Δw and length (r_{max} - r_{min}) as follows [4].

$$q_{NLOS} = \frac{\Delta w(r_{max} - r_{min})}{\pi(r_{max}{}^2 - r_{min}{}^2)} = \frac{\Delta w}{\pi(r_{max} + r_{min})} \tag{10}$$

The probability that the direct wave is not cut off by N_{person} people, a_{LOS}, can be expressed as follows.

$$\alpha_{LOS} = (1 - q_{NLOS})^{N_{person}} \tag{11}$$

By using Eqn. (5) and Eqn. (11), the probability of the received level $E(t,x)$, used in Eqn. (1), can be expressed as follows.

$$p_{LOS}(r_P) = \left(\alpha_{LOS}\, p(r_P, K_{LOS}) + (1 - \alpha_{LOS})\, p(r_P, K_{NLOS})\right) / \, p_{Norm} \tag{12}$$

where p_{Norm} represents the normalization factor that adjusts the cumulative probability to 1.

4. Results

In the calculations, we set Δw, v and N_{person} to 0.3m, 1m/s and 8, respectively. For the case without a direct wave, which means $|e_0(x)| \to 0$, r_{min} and r_{max} are set to 3m and 7m, respectively. For the case with a direct wave, r_{min} and r_{max} are set to 1m and 5m, respectively. We carried out measurements in our laboratory replicating the conditions used in the calculations. Our laboratory space is a rectangular room; two walls consist of glass. This room holds common office equipment such as desks, tables, and shelves. The carrier frequencies are 1.5GHz for without a direct wave and 5.2GHz for with a direct wave, respectively. The Rx antenna is omni directional in the horizontal plane. We made people walk around the received antenna at the constant speed of about 1m/s and measured the received level variation.

Fig.5 shows an example of the measured received level variation for the case without a direct wave. The parameter is the magnitude of $|e(x)|^2$ presented in Eqn. (7). We find that the measurement results are very similar to the simulation results in Fig. 3.

Fig. 6 shows the cumulative probability of calculated and measured received levels with $|e(x)|^2$ as a parameter.

Fig. 7 shows an example of the received level variation with a direct wave. The parameter is the magnitude of $|e_0(x) + e(x)|^2$ presented in Eqn. (6). In this measurement, the ratio of the direct wave power $|A_0|^2$ to multipath power $|e_0(x) + e(x)|^2$ was about 7dB. Fig. 8 shows the cumulative probability of calculated and measured received level with $|e_0(x) + e(x)|^2$ as a parameter.

From Fig. 6 and Fig. 8, we find that the proposed model is in good agreement with the measured results.

5. Conclusion

We proposed a physical channel model for static terminals used in the indoor NLOS and LOS conditions. We compared the analysis results of proposed model with measured results and show that proposed model is in good agreement with the measured results. This confirms that the proposed model is valid for both NLOS and LOS conditions.

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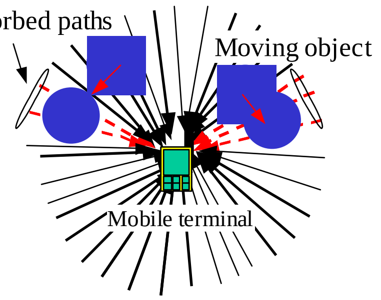


Fig. 1 Proposed model

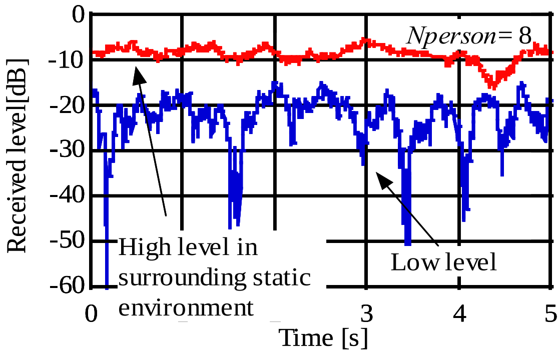


Fig. 2 Received level (Simulation).

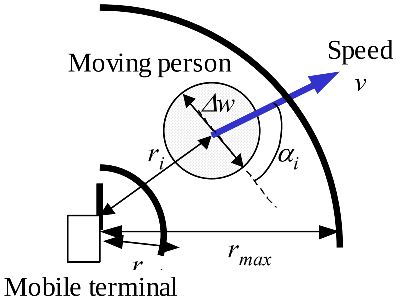
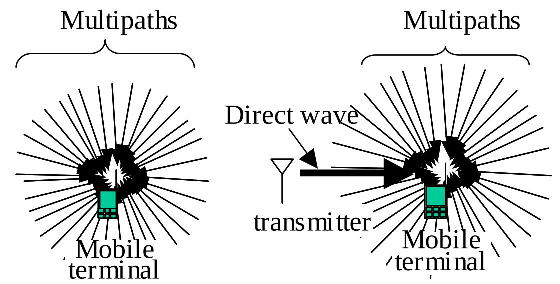


Fig.3 Analysis model.



(a) NLOS condition (b) LOS condition

Fig. 4 Modeling of surrounding moving environment.

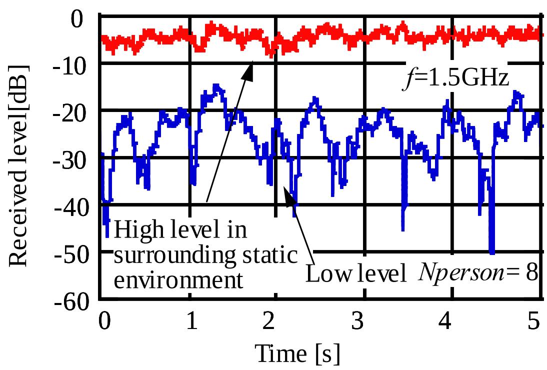


Fig. 5 Measured received level without direct wave

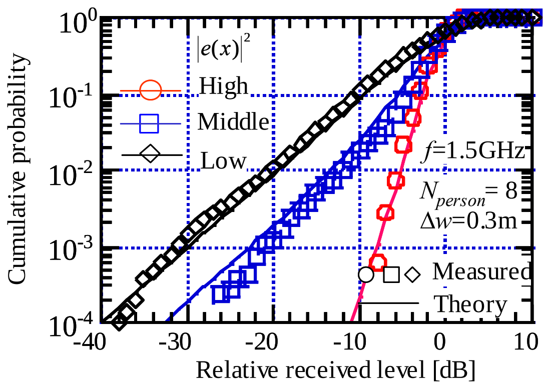


Fig.6 Cumulative probability without direct wave

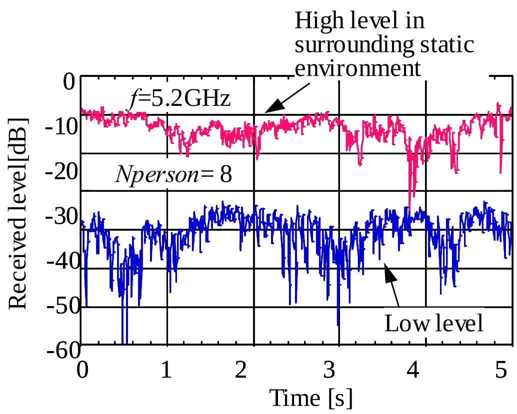


Fig. 7 Measured received level with direct wave

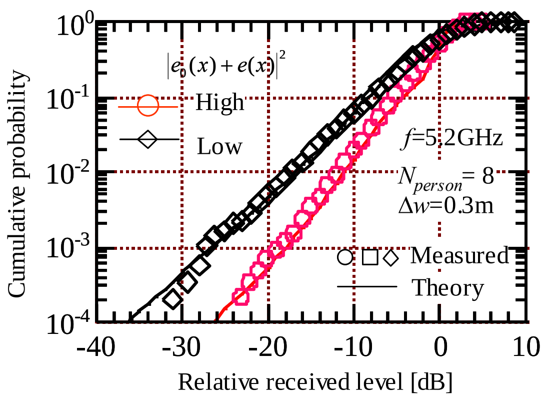


Fig.8 Cumulative probability with direct wave.