An SBR/Image Approach to Indoor Radio Propagation Modeling

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I. Introduction

Detailed understanding the radio propagation characteristics in a room will help the design of personal communication services (PCS) systems. There are two methods that have been applied to analyze this problem. The first is the image theory [1], which is efficient, but can handle simple environments only. The second is the ray tracing technique [2][3], which is powerful for complex environments, but a reception sphere has to be introduced to determine the rays that reach the receivers [2][3][4], and the computed results are sensitive to the radius of the reception sphere. In this paper, a deterministic model using a modified shooting and bouncing ray (SBR) technique [5] is used to model the indoor radio propagation channels. This method can deal with complex environments, and the reception sphere is not needed. Conceptually we use the SBR method to trace ray tubes bouncing in the indoor environments. If the receiver is within a ray tube, the corresponding equivalent source (image) and its contribution to the received field at the receiver (Rx) can be determined. By summing all contributions, we can obtain the total received field at Rx.

II. The SBR/Image Method

To illustrate our SBR/Image method, let us consider a room shown in Fig.1. The transmitting antenna (Tx) is a Hertzian dipole $\vec{P}_0$ which radiates in all directions in the room. The receiving antenna (Rx) is another Hertzian dipole $\vec{P}_r$. We shoot many ray tubes from Tx (Fig.2), and trace each ray tube which bounces in the room. For each bounce, we check whether the Rx falls within this ray tube. If it does, the contribution of the ray tube to the receiver can be attributed to an equivalent source (image). The image position $\vec{\rho}_{oq}$ and the equivalent Hertzian dipole $\vec{P}_q$ of the image related to the q 'th bounce of the ray tube can be calculated by

$$\vec{\rho}_{oq} = \vec{\rho}_q - \ell_q \cdot \hat{\zeta}_q \quad (1)$$

$$\vec{P}_q = (-R_v \hat{\zeta}_q \hat{\zeta}_{q-1} + R_v \hat{e}_{||} \hat{e}'_{||} + R_h \hat{e}_{\perp} \hat{e}'_{\perp}) \cdot \vec{P}_{q-1} \quad (2)$$

where $\vec{\rho}_q$ is the reflecting point of the center ray of the tube at the q 'th bounce and ℓ_q is the path length from Tx to the reflecting point. $(\hat{\zeta}_{q-1}, \hat{e}'_{||}, \hat{e}'_{\perp})$ and $(\hat{\zeta}_q, \hat{e}_{||}, \hat{e}_{\perp})$ are orthonormal bases, generated by the direction of the incidence $\hat{\zeta}_{q-1}$ and the direction of the reflection $\hat{\zeta}_q$, respectively (Fig.3). R_h and R_v are the reflection coefficients for horizontal and vertical polarizations. Using reciprocity theorem, the receiving amplitude b4 [6] contributed by this image at Rx can be calculated. Repeat tracing the ray tube until the number of bounces is larger than the maximum number of bounces set beforehand. The square of the magnitude of the total b4 will equal the ratio of Pr to Pt, where Pr is the power received by Rx and Pt is the total power transmitted in free space by Tx.

II. Numerical Results and Discussions

As a preliminary validation of our approach, we consider a vertical electric dipole $Id\hat{y}$ located in a rectangular corridor with PEC walls. The operating frequency is 1 GHz. Assume that the transmitter is fixed at (x_t, y_t, z_t) , while the receiver at (x_r, y_r, z_r) moves horizontally. The obtained P_r/P_t in dB by the exact modal theory (dashed line) and by our SBR/Image method (solid line) are shown in Fig.4. The agreement is very good between the two methods. In Fig.5, simulation results at the same frequency for a box-like room with PEC walls are shown. The room is 10-meter wide, 21-meter long and 4-meter high. The dielectric constant of the medium in it is $\epsilon_r = 1 - j0.005$, where a small loss is introduced to reduce the number of bounces. The solid line is computed from our SBR/Image method, and the dashed line is calculated on the conventional image theory. Both results agree so well that we have to shift the SBR/Image result by 3 dB to tell the difference. The SBR/Image curve (contains 1001 points) is generated in a shared SUN SPARC 10 workstation within several hours. In Fig.6, simulation results for a room with a window (Fig.1) are presented. The dimension of this room is $10 \times 21 \times 4 \text{ m}^3$. The thickness of the walls is 25 cm with the dielectric constant $\epsilon_r = 6$ and the conductivity $\sigma = 0.01 \text{ S/m}$. The reflectivities of the walls are shown in Fig.6(a). Fig.6(b) is the result by the SBR/Image method at 1 GHz.

In summary, an SBR/Image approach to investigate the radio wave propagation in rooms has been proposed. It can provide a good model of the radio propagation inside a room. The concept of the reception sphere is not needed, and the results are not sensitive to the size of each ray tube. This method can be applied to more complicated indoor environments. More results will be shown in our presentation.

References

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Fig. 1: A room with windows.

Fig. 2: Ray tube shooting from transmitting antenna (TX).

Fig. 3: Ray tube bouncing at a plane interface, and the image source has contribution to the receiving antenna.

Fig. 4: Normalized received power versus z_r in a rectangular corridor with perfect electric conductor walls by modal theory and SBR/Image method. $(x_t, y_t, z_t) = (1.1, 2.1, 0)$, $(x_r, y_r, z_r) = (1.9, 1.7, z)$. Operating frequency $f = 1$ GHz.

Fig. 5: Normalized received power versus z_r in a rectangular room with perfect electric conductor walls by conventional image theory and by SBR/Image method, $(x_t, y_t, z_t) = (1.1, 2.1, 2)$, $(x_r, y_r, z_r) = (6, 1.5, z_r)$. Operating frequency $f = 1$ GHz.

Fig. 6: (a) The reflectivities of the walls in the room. (b) Normalized received power versus z_r in the room shown in Fig.1 by SBR/Image method, $(x_t, y_t, z_t) = (1.1, 2.1, 2)$, $(x_r, y_r, z_r) = (6, 1.5, z_r)$. Operating frequency $f = 1$ GHz.