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Novel usage of binary tree in SBR algorithm for efficient indoor propagation analysis

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Abstract: This letter proposes new usage of the binary tree constructed by fundamental GO ray components in shooting and bouncing rays (SBR) for indoor propagation analysis. The node number of the binary tree is here considered as an important parameter. A couple of small size arrays that can store the passing ray information of both the node number and the position of the pixel considered, and the corresponding ray classification algorithm are newly introduced, not to double-count the same ray with slightly different bouncing angle. Consequently, we realize the big reduction of the computer memory resources consumed for the ray classification especially for wide area analysis, keeping the high accuracy of the SBR method.

Keywords: ray tracing method, shooting and bouncing rays, ray launching method, binary tree, node number, memory reduction

Classification: Electromagnetic theory

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1 Introduction

Shooting and bouncing rays (SBR) [1] or ray-launching method has been widely utilized in research for analyzing wireless communications link [2, 3]. Recently, in developing the next generation wireless networks like cluster based multi-hop system [4], demands for wide area propagation analyses become much larger than before.

In this letter, new usage of the logical binary tree constructed by fundamental GO ray components is proposed, to reduce the required computer resources for wide indoor area propagation SBR analysis. We have shown a novel usage of the node number of the binary tree in our previous work [5], *i.e.* by referring each node for identifying a specific ray with its propagation history (reflection/transmission number of times and its sequence). Here, in order to efficiently identify and not to double-count each ray when multi-rays arrive into a pixel for any shooting angle, we introduce a couple of new small size arrays that can store the information of the pixel position, and the corresponding ray classification algorithm. The proposed ray classification algorithm is based on considering the fact that the ray passing pixel is uniquely labeled either by the x (i) position or the y (j) position, when the shooting direction is limited in each 45° angular range.

Finally, the big reduction of the computer resources consumed for the ray classification is realized. It is also verified by comparing the numerical results of proposed SBR method with those of the FDTD method that the high accuracy of the SBR method is still retained for simple indoor model.

2 SBR algorithm using the geometrical ray components

For indoor EM wave propagation problem inside office or campus buildings, many flat walls, which divide the indoor space into some parts of rooms, may be regarded as dominant scatterers. Here, the walls inside the buildings are considered as homogeneous finite dielectric plate. Based on the ray theory, in addition to direct ray, the line source may produce the reflected, transmitted, and diffracted rays due to the finite object. In present analysis, the three fundamental GO components except the diffracted ray are only considered for proposing a new efficient SBR algorithm.

Let us suppose that in a two-dimensional indoor environment, there is a line current source as a transmitted antenna with omni-directivity, as depicted in Fig. 1 of Ref. [6]. The ray at any position is shown as

$$\phi = \frac{e^{i(k_0 L+\pi/4)}}{\sqrt{8\pi k_0 L}} \prod_{M} \Gamma(\theta_i^{(M)}) \prod_{N} T(\theta_i^{(N)}) \tag{1}$$

Here, k_0 is wave number in free space, and L is the total optical path length of the ray. M and N are the total reflection and transmission number of times,

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$\Gamma(\cdot)$ and $T(\cdot)$ are the corresponding appropriate reflection and transmission coefficients including the attenuation factor $e^{-k_0\alpha_{te0}d}$ at/through the lossy wall, where d and α_{te0} are the thickness and the attenuation constant for the wall considered [6]. $\theta_i^{(M)or(N)}$ is the incident angle relative to the surface normal of the wall.

2.1 Construction of binary tree for a shooting angle

Now, when diffracted ray is not dominant and then it is not included in indoor wave propagation analysis, a physical propagation model for a shooting angle can be considered as the logical (non-physical) binary tree construction with the source as root, as shown in Fig. 1 (a).

Each branch of the tree represents the reflected or transmitted ray to the originated node or the node of the parent generation. For every node and generation in the tree construction, the node number m and the generation number n are provided as in Fig. 1 (a). The relationship of the maximum node number m_{max} to each generation step n is $m_{max} = 2^n - 1$.

A reference node number m generates the next generation node number $2m$ or $2m+1$, which corresponds the reflected or the transmitted rays. Therefore, referring the number for each node, one can easily obtain the information on the ray's species (reflected or transmitted ray), and the propagation history (total reflection/transmission number of times and its sequence) [5]. For example, it is readily found from a comparison between Fig. 1 (a) and (b) that 'ray A' toward the node '12' experiences 2 times reflections and 1 time transmission, and its sequence is as "direct → transmission → reflection → reflection."

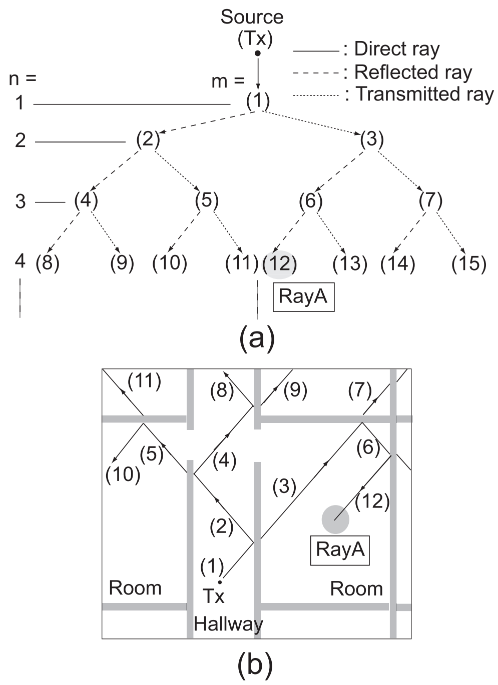

Fig. 1. Binary tree for a shooting ray with a source (Tx) as root for reflected/transmitted rays (a) Binary tree (b) The corresponding propagation model.

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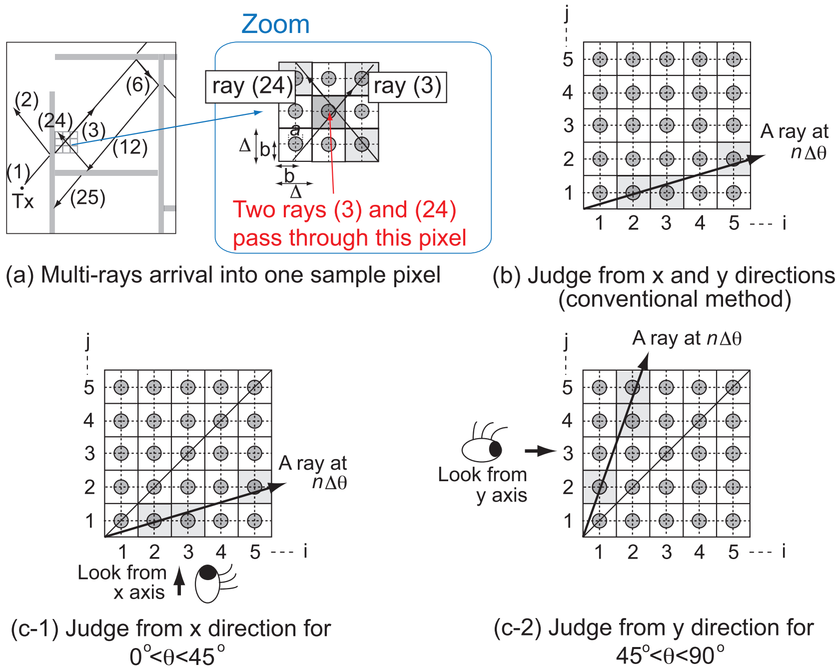

Fig. 2. Classification of the multi-rays incident into a pixel of position (i, j).

2.2 Memory size reduction in ray classification process

In indoor space surrounded by walls, there are many rays with multiple reflections and multiple transmissions. They sometimes pass through a pixel any number of times. For example, Fig. 2 (a) shows that two rays with $m = 3$ and $m = 24$ pass through a pixel. Also, the rays go through a pixel with slightly different bouncing angle must not be double-counted. To estimate and visualize the result of the SBR analysis for any observation locations, accurate classification of such passing-through rays at the pixel is needed.

In our previous work [5], to distinguish each ray, we utilize the node number 'm' of the binary tree via the following algorithm.

1. Prepare an integer array $c(i_{max}, j_{max})$ for ray classification. Here, i_{max} and j_{max} are the maximum pixel size for x and y directions in the analytical region, respectively.

2. Initialize the array, $c(i, j) = 0$.

3. Compare between the node number 'm' of the tracing ray and the value of '$c(i, j)$' for the pixel considered. If m does not equal to $c(i, j)$, then m of the current ray is assigned to the array variable $c(i, j)$. For the ray in Fig. 2 (b), if $m = 3$, then $c(2, 1) := 3$, $c(3, 1) := 3$, and $c(5, 2) := 3$. Here ':=' means the assignment statement in the programming language.

4. Consequently, by repeating this process and referring the latest node number, one can classify the current tracing ray from previous ones at the pixel (i, j) considered.

To realize this algorithm, however, the array $c(i_{max}, j_{max})$ must be prepared for entire analytical region. So, in addition to that for the field calculations,

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the extra computer resources, '$i_{max} \times j_{max} \times 2$ (int) bytes', are required only for the ray classification. For example, when the analytical region is constructed by 10,000 × 10,000 pixels, then the extra 200 Mbytes memory is required.

In this research, to avoid such undesired memory consumption, we propose a new ray classification algorithm using 'm' of the binary tree. Here, we shall see a fact that the generation 'n' of the binary tree is practically considered up to 5 or 6, i.e. the maximum node number 'm_{max}' is up to 15 or 31. For convenience of the discussion, let us consider only the 1st quadrant of the shooting angular range, $0° \leq \theta < 90°$, from now on.

In Fig. 2 (b) and (c-1), a tracing ray is depicted in the angular range $0° \leq \theta < 45°$. The ray passes through the pixels at the same positions $(i, j) = (2, 1), (3, 1)$, and $(5, 2)$. From a perpendicular viewpoint, one can recognize that these pixels are uniquely labeled by the x (or i) position, although they are not unique for the y (or j) position. On the other hand, in the range $45° \leq \theta < 90°$ of Fig. 2 (c-2), from a horizontal viewpoint, the ray passing pixels can be uniquely labeled by the y (or j) position, instead of the x (or i) position. Accordingly, taking into account this feature, a novel ray classification algorithm is proposed as follows.

1. Prepare a couple of integer arrays $cx(i_{max}, m_{max})$ and $cy(j_{max}, m_{max})$.
2. Initialize the arrays, $cx(i, m) = 0$ and $cy(j, m) = 0$.
3. For $0° \leq \theta < 45°$ (or $45° \leq \theta < 90°$), compare between the y position 'j' (or the x position 'i') of the passing pixel and the value of '$cx(i, m)$' (or '$cy(j, m)$'). If j (or i) does not equal to the value of $cx(i, m)$ (or $cy(j, m)$), then m of the current ray is assigned to the array variable $cx(i, m)$ (or $cy(j, m)$). In other case, no assignment is carried out.
4. By repeating this process for any shooting angle θ, one can readily and quickly classify the current tracing ray at the pixel considered.

By applying the present new algorithm using the small arrays '$cx(i, m)$' and '$cy(j, m)$', the required memory size for the ray classification is only

$$(i_{max} \times m_{max} \times 2) + (j_{max} \times m_{max} \times 2) = (i_{max} + j_{max}) \times m_{max} \times 2.$$

When the analytical region is 10,000 by 10,000 pixels and the maximum node number $m_{max} = 31$, the consumed memory size becomes only 1.24 Mbytes.

3 Validity of the proposed algorithm

To confirm the validity of the present SBR algorithm including the new ray classification algorithm, let us finally show the simulation results.

Fig. 3 (a) shows the simulation result of the field strength map for a simple indoor model using the proposed SBR algorithm. The analytical region is 20 m × 20 m, each room area is 6 m × 9 m, and the width of the hallway is 3 m. All walls are made of flat dielectric plate, whose thickness d is 0.2 m and relative permittivity ε_r is $2.0 + i1.2$. A line current source or transmitted

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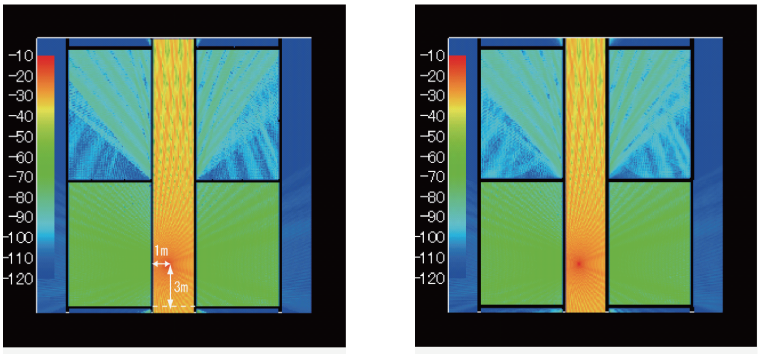

(a) SBR method (b) FDTD method

Fig. 3. Comparison between the present SBR and FDTD methods.

antenna with 2.4 GHz frequency is set at the hallway region (3 m from the bottom, 1 m from the adjacent left wall). In the SBR simulation, the square pixel size is set as $\Delta = 0.05\lambda_0$, and the shooting angle step is $\Delta\theta = 0.01^o$. The reception circle diameter a is automatically determined by the optical path length [3]. Total reflection/transmission number n_{max} is set as 5. As the reference, the result of the FDTD analysis is also shown in Fig. 3 (b).

It is verified from a comparison between the present SBR and FDTD results that very similar propagation tendency can be observed. The required total memory size for the present SBR analysis is reduced down to about 100 Mbytes from 120 Mbytes of the conventional one. On the other hand, the FDTD simulation requires about 320 Mbytes. Computational time of the present SBR method is 3 minutes, whereas the FDTD method spent 10 minutes (Intel Core i7 2.67 GHz, single thread). It is confirmed from these results that by using the present SBR algorithm, accurate indoor propagation analysis can be realized under small computer resource environment.

4 Conclusion

We have proposed new usage of the binary tree constructed by fundamental GO ray components in SBR indoor propagation analysis. To classify each ray when multi-rays arrive at a pixel, a couple of new small size arrays that can store the information of both the node number and the position of the pixel considered, and the corresponding simple ray classification algorithm are introduced, Resultantly, it is confirmed by comparing the present SBR result with both conventional SBR and the reference FDTD results that the reduction of the computer resources due to the improvement of the ray classification process is realized, whereas the accuracy of the propagation analysis is retained.

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