AN EFFICIENT RAY TRACING TECHNIQUE FOR MICROCELLULAR PROPAGATION MODELING USING THE IMAGE APPROACH*

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ABSTRACT

A ray tracing technique for treating multiple reflection is proposed using the image approach. Criteria are given for identifying which of the ray candidates will contribute to the received signal. Some geometrical and physical restrictions are introduced and the number of ray candidates are greatly reduced. Ray tracing results and signal path-loss for some typical urban settings are presented.

1. Introduction

With the rapid growth of microcellular communications, there has been growing interests in studying the propagation models for urban settings [1]-[6]. Attention has been paid to ray tracing techniques since they are the key objects in field or path-loss prediction [2][5][6]. Of which the image approach has advantages in that the ray path can be exactly determined and thus leads to accurate results [5]. Unfortunately there is an obvious pitfall in the image approach, *i.e.*, the number of ray candidates is much large when we want to trace rays with multiple reflections and the number of reflection walls is considerably large. For example, assuming there are 6 reflection walls, we have to scan 14,648,436 candidates for tracing rays with maximum 10 reflections. On the other hand, our experience shows that in this case the number of valid rays, *i.e.*, the rays which contribute to the received signal, is no more than about 10 ~ 20. This means that the usual image approach is inefficient or even inapplicable in some cases.

This paper focuses on the improvement of the image approach. By using images of the receiver two criteria are proposed to determine whether a ray candidate is valid or not. Some geometrical and physical restrictions are introduced and the number of ray candidate is greatly reduced. It is shown that our approach can be applied to more general urban settings efficiently and accurately.

The propagation environment is shown in Fig.1 is two-dimensional for the sake of clarity and our techniques work in three-dimensional cases. Buildings in the figure may be non-rectangular but we have chosen the simplest case only to simplify the exposition.

2. Criteria for Identifying Valid Rays

In the image approach the ray candidates can be exactly determined when the images of the receiving antenna R_x are given. For instance, the image of R_x in Fig.2, denoted R(1), uniquely defines a candidate. In general, a ray candidate with n reflections can be uniquely represented by a series of sequential n images, *i.e.*, {R(n), R(n-1), ... ,R(i), ... , R(1)}, where R(1) is the image of R_x and R(i) is the image of R(i-1) with $2 \le i \le n$. R(i) is called the ith level image of R_x for convenience.

The ray tracing procedure for a candidate with n reflections has at most n steps to determine the n

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reflection points in the ray. In the first step, we connect the transmitting antenna T_x with R(n) to obtain a segment $T_xR(n)$. The first reflection point P(1) is then the intersection point of $T_xR(n)$ with the wall associated with R(n). In the ith ($2 \le i \le n$) step, we connect the (i-1)th reflection point P(i-1) with the (n+1-i)th image R(n+1-i) to determine the ith reflecting point.

If there exists no reflection point at all in a ray tracing step of a candidate, the tracing procedure should be stopped and this candidate is an invalid ray. On the other hand if the n reflection points are successfully found out the candidate is thus a valid ray, *i.e.*, it contributes to the receiving antenna. There are two criteria for determining if a ray candidate is invalid.

1. For each step in tracing a ray candidate, if the segment defined by $T_xR(n)$ (for the first step) or P(i-1)R(n+1-i) (for the ith step, $2 \le i \le n$) does not intersect with the reflecting wall associated with R(n) or R(n+1-i), respectively, the candidate is invalid.

2. If, in a step of ray tracing, we have obtained an intersection point P(1) (for the first step) or P(i) (for the ith step) we must check whether the segment $T_xP(1)$ or P(i-1)P(i) intersects any obstacles. If it does we conclude that this ray segment is obstructed and thus the ray candidate is not valid.

3. Reduction of Ray Candidates

We have known that a ray candidate can be represented by a sequence of images. This sequence can further be represented uniquely by the image R(n). In fact, the number of ray candidates is equal to the number of total images. Suppose there are m reflecting walls and the maximum number of reflection points in a ray candidate is n. The total number of ray candidates or images is

$$M = m + m \times (m-1) + m \times (m-1)^2 + \cdots + m \times (m-1)^n = m \times (1-(m-1)^n)/(2-m)$$

A short list given in Table 1 shows M versus n for m=6. It can be seen that M varies with m^n when m is large. It is clearly inefficient or even impossible to trace out so large amount of ray candidates Fortunately the number of ray candidates can be greatly reduced by introducing some geometrical and physical restrictions.

Restriction 1. Only those reflection walls which are visible to R_X may reflect rays directly to R_X.

This restriction states that if the first level image in a ray candidate is not associated with any wall visible to R_X, the candidate must be invalid.

Restriction 2. A ray candidate represented by R(i) can never be a valid ray if R(i) is not associated with any wall visible to T_X.

The power emanated from the transmitter flows in direction to the receiver along the streets. This observation is also useful in reducing the number of ray candidates.

Restriction 3. A reflection wall W can receive rays reflected from those walls which are visible to W and at the same time the power flow is in the direction from these walls to W.

Consider a typical path of power flow shown in Fig 3. Though W6 is visible to W4, W4 would not receive rays reflected from W6 since the power flow is in direction from W4 to W6.

The combination of the above three restrictions may greatly reduce the number of ray candidates. For the street system in Fig 3 with 6 reflection walls, we calculated the number of ray candidates M_c under these restrictions for each n, see Table 1. The number of valid rays are also listed there. It is noted that for n=15, M_c is about 8 orders of magnitude smaller than M.

4. Results and Discussions

We give two typical ray tracing results of our method in Fig. 4. The maximum number of reflections in the ray candidates for both case is 20 and the valid rays are 13 and 5 respectively

We also calculated the signal path-loss along the street in New York [2], see Fig. 5. We observe that for line-of-sight (LOS) region our results is in good agreement with the measurements in [2]. On the other hand our result is not so satisfactory for out-of-sight (OOS) regions. This is due to the fact that the diffracted rays should be taken into account in these regions. We also note that when the distance between T and R is greater than 240 meters, there are no reflected rays at all.

5. Conclusion

The results in the paper shows that the number of ray candidates can be greatly reduced by introducing some geometrical and physical restrictions. The ray tracing technique using image approach is thus made more efficient in treating urban street systems where the usual approach may be inefficient or even inapplicable. Our results also show that for the calculation of path-loss in LOS region the diffraction effect is not significant and may be neglected.

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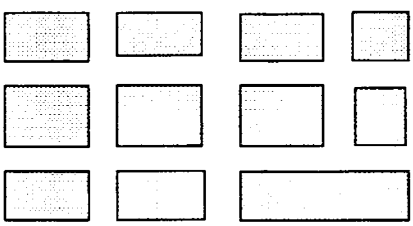


Fig.1. A model urban site

Table 1. Numbers of ray candidates and valid rays for n=6

n	M	M_c	valid rays
1	6	4	0
5	4686	61	4
10	14648436	190	10
15	4.6×10^{10}	507	10

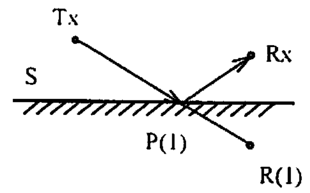


Fig.2. A ray with 1 reflection

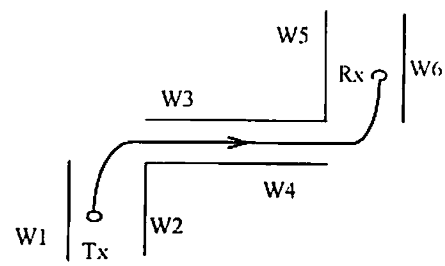
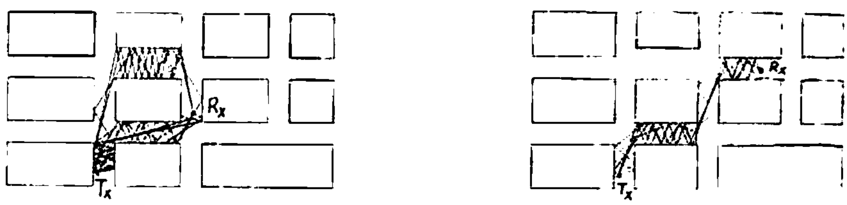
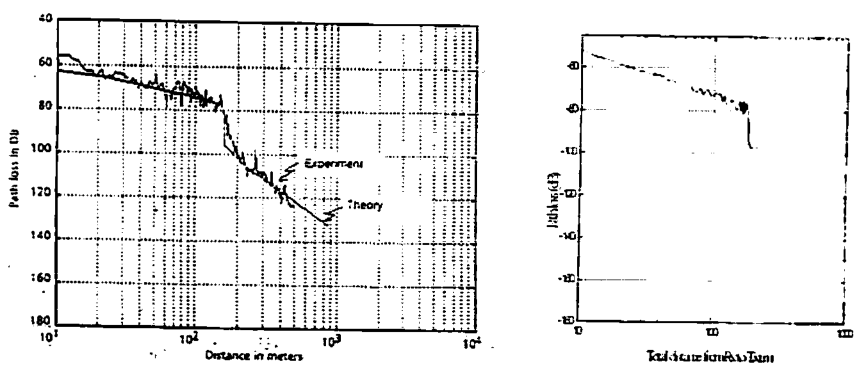


Fig. 3. A typical path power flow



(a) (b)

Fig. 4. Two typical ray tracing results



(a) Results in [2] (b) Results of this paper

Fig. 5. Path loss characteristics (New York street site)