High-precision Propagation Estimation | High-speed Computation | Area Design

Technology Reports

Ray-tracing Method for Estimating Radio Propagation Using Genetic Algorithm

Tetsuro Imai

We propose a GA ray-tracing method which applies a genetic algorithm to ray tracing in order to complete the large-scale computation of estimating radio propagation in a practical amount of time. We describe the GA ray-tracing method as well as a demonstration of its effectiveness through numerical simulation.

1. Introduction

In mobile communications systems, it is extremely important to be able to estimate radio propagation, and in particular, propagation losses to obtain reception power, for system design, and cell planning[*1]. Conventionally, the Okumura-Hata equation has been used for estimations when the base-station antenna is higher than the surrounding buildings [1]. The Okumura-Hata equation only uses four parameters: transmitter-to-receiver distance, frequency, base-station-antenna height, and mobile-station-antenna height; so it is quite an easy method to use. However, this method was derived experimentally, by statistically analyzing measurement data, so it can only be applied within the following limits: transmitter-to-receiver distance from 1 to 20 km, frequency from 150 to 1500 MHz, base-station-antenna height from 30 to 200 m, and mobile-station height from 1 to 10 m. In recent years, with the proliferation of mobile terminals (mobile phones), expansion of coverage areas, and improved quality, base-station antennas are no longer necessarily placed higher than the surrounding buildings. On the other hand, as high-rise buildings increase in urban areas, regions have appeared where reception from existing base stations has degraded, blocked by surrounding buildings, or new "Fukiage stations" (base station that directly cover a specific building from the outside) have been installed to bring these buildings into the coverage area (**Figure 1**). In these types of cases, the Okumura-Hata equation cannot be applied, and an estimation method that reflects the actual terrain and features is needed [2][3].

Ray-tracing methods have been used effectively for rendering (generat-

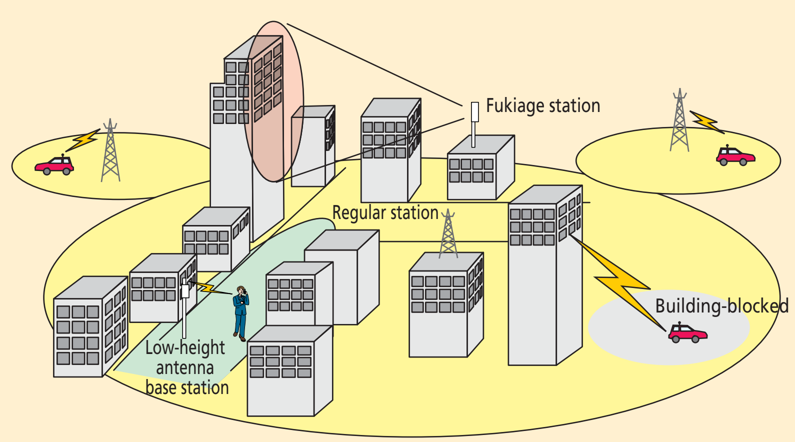


Figure 1 Recent mobile communication environments

*1 **Cell planning**: The area that a single base station is responsible for is called a cell, and the process of planning how to cover a desired service area using multiple cells.

ing images or animations) in the 3D computer graphics field [4]. In the radio propagation field, many years of study have gone into creating practical methods based on ray-tracing for making estimations that reflect the specific environment [1]. An overview of a ray-tracing method for estimating radio propagation is shown in **Figure 2**. Radio waves emitted from the transmitter are treated as rays, which are traced geometrically as they interact with the surrounding objects (reflection, transmission and diffraction) before finally arriving at the receiver. The various propagation characteristics (losses, delay time and arrival angle) are computed using the path length, arrival angle and field-strength of each ray traced. **Figure 3** shows the results of an estimation for the Shinjuku urban area (Frequency: 2 GHz), together with the results from an Okumura-Hata estimation. Note that no correction for the area occupied by buildings has been made in the Okumura-Hata result. In the ray-tracing result the effects of buildings in the estimation area are reflected strongly, as can be seen from the tendency for reception power to be higher along roads and at intersections in Fig. 3 (b).

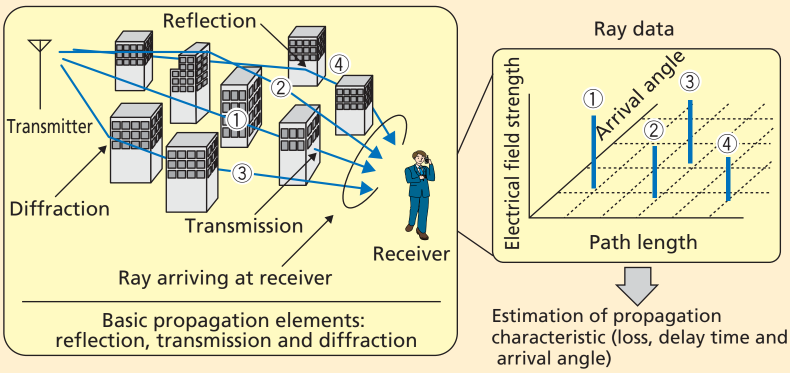
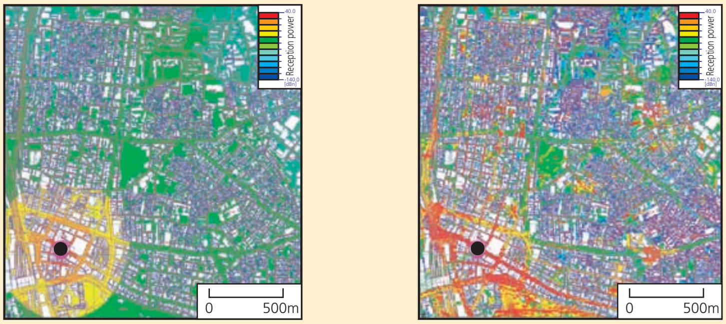


Figure 2 Estimating radio propagation with ray-tracing



(a) Okumura-Hata equation (b) Ray-tracing method

Figure 3 Example of propagation estimation result

This ability of ray-tracing methods to estimate propagation characteristics in a unified way for various types of environment is extremely promising. However, there is a trade-off between precision and computation time with ray tracing, and if the upper limit of area size and number of buildings interacted-with is set high, the amount of computation required for a precise estimation increases very rapidly. Due to this, increasing computation speed has been one of the major issues with ray-tracing methods.

In this article, we describe a method in which Genetic Algorithms (GA)*2 [5] are applied to ray tracing, making it possible to achieve dramatic improvements in ray-tracing processing speed. The new method is called the GA-Ray-Tracing method [6] (or GA_RT). We also demonstrate the effectiveness of this method with numerical simulation.

2. Speed up of the Ray-tracing Processing

In this chapter, we describe our approach to increasing the processing speed for ray tracing.

There are three main approaches used to increase processing speed for ray tracing: 1) optimization of computation, 2) speed up of algorithm, or 3) distribution of computation. We will describe the accelerated system that was developed, called Urban Macrocell

*2 **GA**: An algorithm which models how living things adapt and evolve. Pioneered by John H. Holland of Michigan University.

Area Prediction system (UMAP) [7] in terms of these approaches.

1) Optimization of computation

Under this approach, we applied limits to parameters of the computation based on knowledge and experience obtained thus far. These include "range of physical structures considered" and "number interactions set." If the hypothesized propagation model is appropriate, the computation can be completed omitting rays that do not contribute significantly to the propagation characteristic, eliminating a large part of the computation required, while minimizing degradation to the precision of the result. The Sighted-Objects-based Ray-Tracing (SORT) method shown in **Figure 4** is equivalent to that used in UMAP. We use the Imaging method[*3] to limit tracing to buildings and structures visible from the Base Station (BS) or Mobile Station (MS), supposing that rays propagate from BS to buildings visible from the BS, to buildings visible from the MS, and finally to the MS. This reduces the amount of computation dramatically, as the number of propagation paths considered is greatly reduced.

2) Speed up of algorithm

For this approach, we use ray-tracing optimizations exemplified by the Imaging and Ray-launching methods[*4]. Basically, with this approach computations are not approximated, so the precision of the result is not degraded, but pre-processing is usually required before ray tracing. The approach used with UMAP is a visible-building-search method as shown in **Figure 5**, optimizing the process of determining which buildings are visible. Fig. 5 shows how the method creates an approximated search area divided into $\Delta L \times \Delta L \times \Delta H$ search blocks as a pre-processing step, and then when searching for visible buildings, it first looks for visible search blocks. Using this method, multiple buildings can be eliminated in one step, speeding up the computation. The method does not result in selection of non-visible buildings. For details on this method, please refer to [7].

3) Distribution of computation

The final approach, shown in **Figure 6**, distributes ray-tracing computations to several other machines connected on a network. With this approach, there is no degradation of the precision

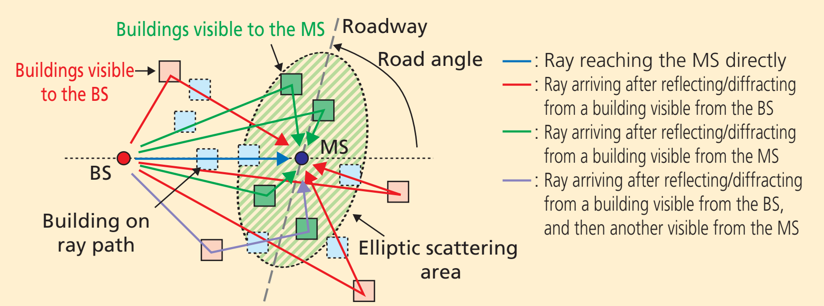


Figure 4 Ray tracing using the SORT method

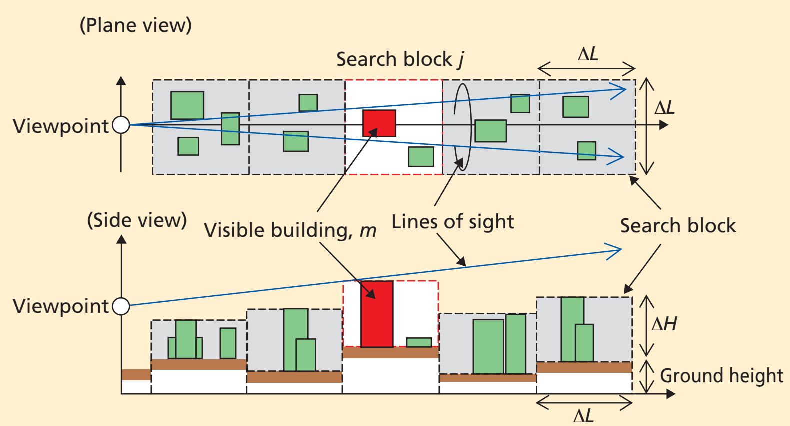


Figure 5 Visible-building-search method

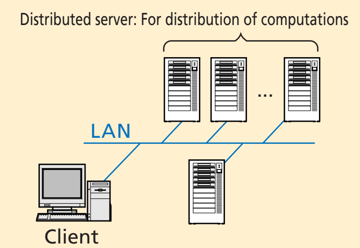


Figure 6 Distribution of computations over several machines

*3 **Imaging method**: A method where the reflections (images) of the source and destination points are used to trace ray-propagation paths.

*4 **Ray-launching method**: A method where rays are emitted from the source point at fixed-interval angles, and the propagation path is traced for each ray.

of the result. Also, as long as it is used in a range where the network transfer speed does not become a bottleneck, the total processing speed will be proportional to the number of machines or CPUs used. Although there is a cost associated with creating the computing environment, this method can yield the most predictable results. If blade-machines[*5] are used as a distributed server, the system can also be built to save space. The authors used over 25 blade quad-core CPU[*6] machines for the UMAP distributed server. In consideration of recent progress with Grid computing[*7], this approach should be quite promising in the near future.

Of the above approaches, the most dramatic improvements are expected from approach 1) Optimization of computation. However, as mentioned above, a basic propagation model is needed for this approach, and most models used till the present have been built and verified based on empirical measurements. Further, a basically universal propagation model does not exist, and models to suit each environment must be prepared. For example, the best propagation models for indoor and outdoor propagation environments are different. With the number of BS configurations and cell architectures increasing as they are, it is very difficult to build all imaginable propagation models needed. However, looking at it a different way, if an algorithm for self-structuring[*8] propagation models suited to the particular environment could be combined with ray-tracing, very effective optimizations should be possible. The GA_RT method described in Chapter 3 uses an algorithm to self-structure the propagation model, focusing on GA methods similar to how animals evolve with their environments to evolve the propagation model to suit the environment.

3. Optimization Through Use of Genetic Algorithms

The GA_RT method presumes the application of the Imaging method to ray-tracing computations. The Imaging method first selects the ray propagation paths from source to destination using a combination of building faces and edges. Then, for each path, an image of the source point (or destination point) is generated, while also searching for interaction points. Final ray tracing is done connecting the source to destination using these interaction points (For details see [1]).

3.1 Basic Model

With GA, chromosomes are defined with genes for different target forms[*9], and individuals[*10] are given concrete values for these genes within a range for the issue being solved, giving them diversity. An individual is expressed as a single combination of these genes, and the total of all these combinations is all of the types of individuals that can be represented. In ray tracing, ray paths are expressed as combinations of faces and edges, and the total of all possible such combinations is the number of possible ray tracing paths that can be calculated, N_{all}. How individuals are expressed in GA, and how paths are expressed in the Imaging method are very similar. This brings our attention to the individual-group model used in GA_RT and shown in **Figure 7**.

In the proposed individual-group model, genes correspond to faces and edges, chromosomes to combinations

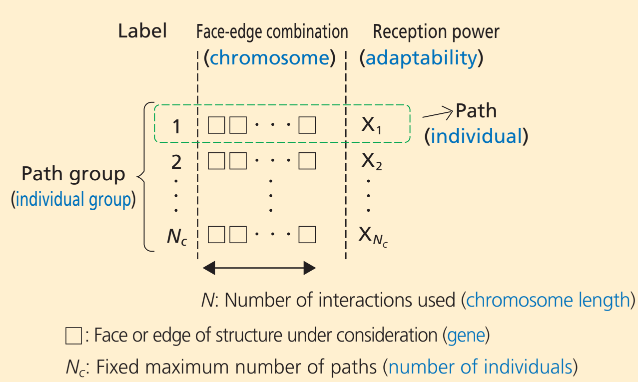


Figure 7 Individual-group model

*5 **Blade-machine**: A server computer consisting of multiple pluggable "Blade" computers in a "Blade chassis" (case) capable of housing them.

*6 **Quad-core CPU**: A CPU with four-CPU cores.

*7 **Grid computing**: Technology which allows multiple computers on a network to be combined, viewed as a single, virtual, high-performance computer for performing computations.

*8 **Self-structuring**: In this article, the independent formation of the propagation model.

of edges and faces that make a path, and individuals to single paths. An individual-group is a group of paths, and the size of this group (number of individuals per generation) is N_c. Then, the basic processing flow of the GA_RT method is as follows. First, N_c combinations are selected randomly from among "all conceivable face and edge combinations" and these are defined as the initial path group (first generation). Then, for each path, the ray is traced, and the reception power is computed. Here, the adaptability[*11] of the individual (path) is defined as the reception power of the traced ray. The paths are then sorted according to adaptability and re-labeled in that order. Then, the result is evaluated to see if it satisfies a set of pre-determined stopping conditions, and if it does not, the path-group is re-constructed (next generation) using GA-specific operations like selection[*12], crossover[*13], and mutation[*14] as shown in **Figure 8**, and the new paths are ray-traced. This is repeated until the stopping conditions are met, and then desired path characteristics (total reception power, delay spread, etc.) are calculated and processing ends. Here, the stopping condition is if the computation ratio (total number of paths computed/total number of possible paths, N_{all}) exceeds a fixed threshold value.

3.2 Chain Model

The chain model is a model used by the GA which assumes that many reception points arranged in planes will be computed. In other words, "area computations" will be done.

The performance of the GA depends strongly on what the initial individual-group is set to be. So, if an appropriate initial group can be set initially, a high-precision result can be obtained with only a small amount of computation. The chain model is one in which the final path-group from the nearest neighbor completed earlier is used as the initial setting for subsequent paths. This is explained further using **Figure 9** below.

First, the computation order for the reception points within the area being computed is defined so that the distance, Δr, between adjoining reception points is as small as possible (computation course definition). Then, reception points are separated into two types:

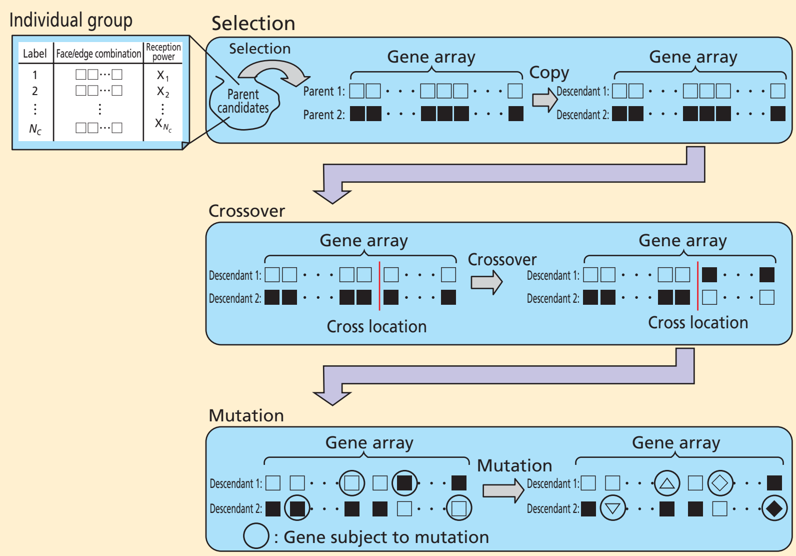


Figure 8 GA Generation update (path reset)

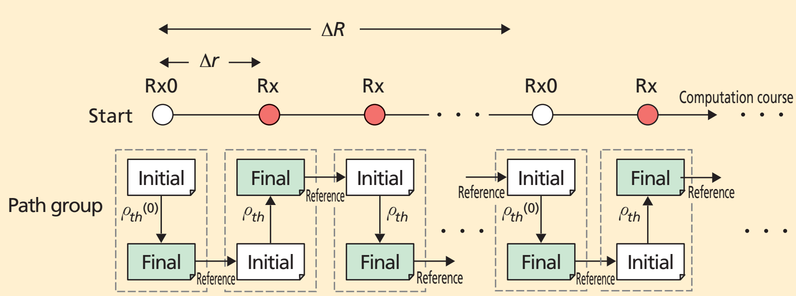


Figure 9 Chain model

*9 **Target form**: The form to which the genes apply. Form refers to a shape or quality of the object, and particularly with living things, to a morphological characteristic.

*10 **Individual**: A single, independent organism.

*11 **Adaptability**: In genetic algorithms, the degree to which an organism is adapted to its environment.

*12 **Selection**: In genetic algorithms, that which models natural selection of organisms.

*13 **Crossover**: In genetic algorithms, that which models how organisms produce descendents through crossover.

- Initial reception points, Rx0: Initial path-group is set randomly according to the basic model.
- Regular reception points, Rx: Initial path group is set to the computed result of the nearest adjacent point (one point previous along the computation course)

Here, ΔR ($\geqq \Delta r$) is the distance between initial reception points, so if $\Delta R = \Delta r$ is set, all points will be initial reception points, and if $\Delta R = \infty$ is set, all except the very first point will be regular reception points. Note that if all points are initial reception points, the chain model is effectively not being applied. Also, $\rho_{th}(0)$ and ρ_{th} are the computing ratio threshold settings for initial and regular reception points respectively, and are basically set such that $\rho_{th}(0) > \rho_{th}$. The processing flow for the GA_RT method when applying the chain model is shown in **Figure 10**.

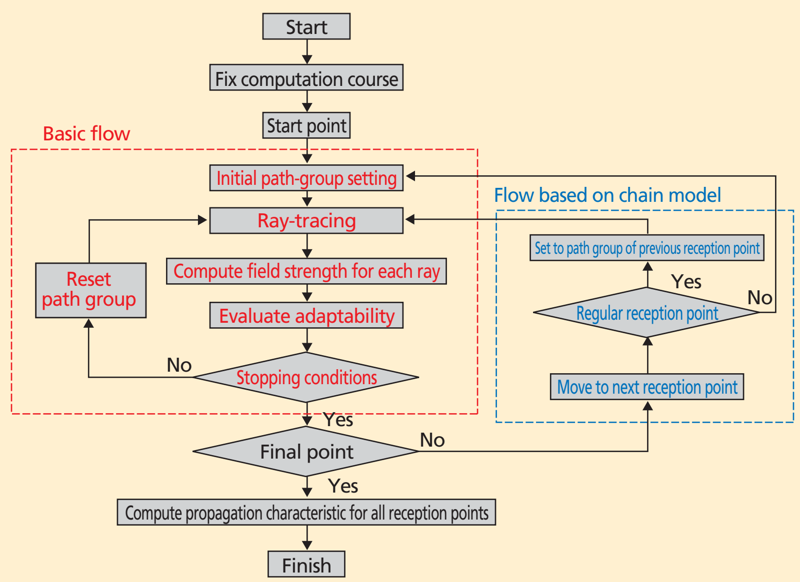


Figure 10 GA_RT method processing flow

4. Effectiveness of Applying the Genetic Algorithm

In this chapter, we evaluate the effectiveness of the GA_RT method using a numerical simulation.

4.1 Evaluation Model

A two-dimensional planar model was used for evaluation. Multiple structures were used, all vertical walls (infinite height, zero thickness and finite width) arranged within a 2 km X 2 km area. Placement and orientation of the walls was random, and each wall was defined in terms of one face and two edges (vertical and with infinite height).

4.2 Computation Conditions

The structures (walls) considered were made of concrete (relative permittivity[*15]: 6.76, electrical conductivity[*16]: 0.0023 S/m) and had a width of 30 m. The number of faces used, M_0, was 50 (total number of faces and edges, M, was 150). Rays were traced through an infinite number of transmissions, and up to two (N) reflections or diffractions. Note that for this simulation, “repeated, consecutive reflections and diffractions within the same wall face” were not allowed. The ray reception power is obtained at a frequency of 2GHz and 10dB per transmission losses[*17] by using Fresnel’s reflection coefficient[*18] as a two-layer medium and the Uniform geometrical Theory of Diffraction (UTD) respectively, for calculation of reflection coefficient[*19] and diffraction coefficient[*20]. See [1] for details on the Fresnel’s reflection coefficient and UTD.

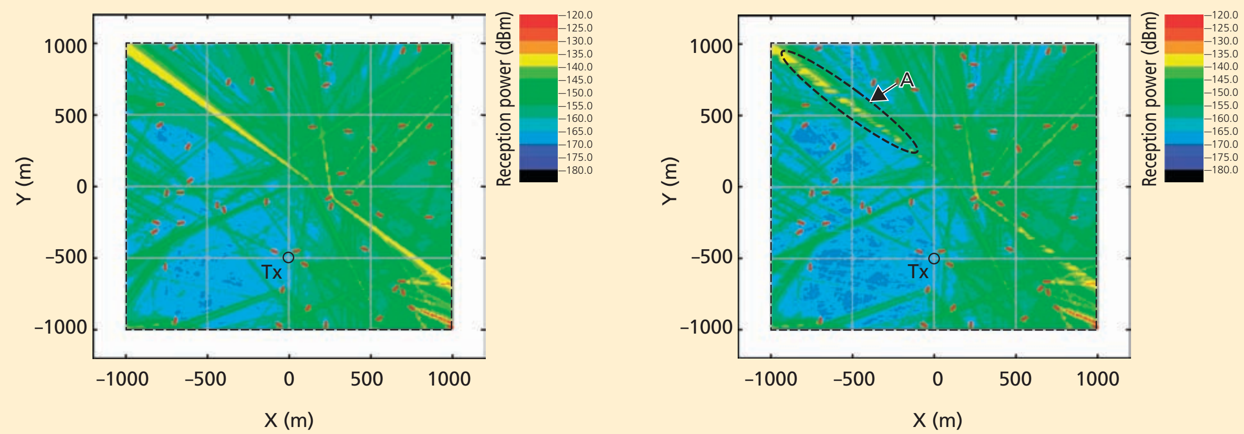
Next we describe the conditions for the GA. The path-group size was set to $N_c = 2MN$. When creating the next generation, entries are stored in consecutive-generation form[*21][5]. Specifically, $N_c/3$ entries from the previous generation that had high adaptability were selected, and added to the next generation as-is. The remaining $2/3N_c$ entries were generated using cross-fertilized from randomly selected entries (cross location selected randomly) and muta-

*14 **Mutation**: In genetic algorithms, that which models structural changes that cause characteristics differing from the parent, as is seen in the genes of living organisms.

*15 **Relative permittivity**: Permittivity is defined as the ratio of electrical flux density to electrical field. When expressing the permittivity of a material, it is generally expressed relative to the permittivity of a vacuum.

*16 **Electrical conductivity**: The reciprocal of the relative electrical resistance (per unit length and area), a value reflecting how easily the material conducts electricity.

*17 **Transmission losses**: Accumulated losses when passing through a material.



(a) Conventional (Imaging method) (b) GA_RT method

Figure 11 Computed results

tion (probability of occurrence: P_m = 0.01). The stopping condition used was the computation ratio, as discussed above, and the value was used as a parameter for the simulation.

4.3 Results

The results using a conventional method (Imaging method) and using GA_RT ($\Delta R = \infty$, ρ_{th} (0) = 0.5, ρ_{th} (0) = 0.05), in the form of an area diagram of reception power, are shown in **Figure 11**(a) and 11(b), respectively. The transmission point, Tx, was placed at (0, –500 m), with the computation course starting at (–1000 m, –1000 m) and inching along the Y-axis. The separation of reception points, Δr, was 10 m, resulting in a total of 40,401 reception points. The red lines in both diagrams indicate the positions of the walls. The area marked ‘A’ in Fig. 11(b) shows that the chain model could not follow changes in the environment well, but overall, the results in Fig. 11 show that the GA_RT is very close to that obtained with a conventional method. Evaluating the error in this result, assuming the result from the conventional method is correct, gives an average rate of 1.23 dB. Also, the average computation ratios were ρ_{th} (0) = 0.5 and ρ_{th} = from 0.05 to 0.06 (See [6] for details). If this error rate of 1.23 dB can be accepted, the GA_RT method provides a speed-up of roughly 17 times (approx. 1/0.06) over the conventional method.

5. Conclusion

In this article we have described a GA ray-tracing method which applies genetic algorithms to ray-tracing computation and is able to achieve a significant reduction in computation-time. The effectiveness of the method was simulated numerically, and evaluating the results showed that a reduction in computation time by a factor of approximately 17 times can be gained if an error rate of 1.23 dB is acceptable.

The GA_RT method can also be used in combination with other optimization methods. We have already completed an implementation of the UMAP propagation estimation system. The main issue to be examined next is to perform a parameter study*22 to make GA_RT work effectively with UMAP and to verify the results.

REFERENCES

[1] Y. Hosoya (Editor): “Radiowave Propagation Handbook, Section 2, Chapter 15,” Realize Corp, 1999 (In Japanese).
[2] M. Fukushige and T. Imai: “A Study on Influence of High-rise Building beside Base Station on Mobile Communication Service Area,” 2007 IEICE General Conference, B-1-9, 2007 (In Japanese).
[3] K. Kitao and T. Imai: “Estimation Model for Received Levels of Incident Waves using Geometrical Optics,” 2007 IEICE General Conference, B-1-8, 2007 (In

*18 **Fresnel’s reflection coefficient**: A fixed formula for reflection coefficient due to the physicist Fresnel. The formula assumes that, if the boundary surface between two media with differing refraction coefficient is smooth and large enough relative to the wavelength, the incident electro-magnetic wave will be a surface wave.

*19 **Reflection coefficient**: Proportion of electrical field modified by reflection.

*20 **Diffraction coefficient**: Proportion of electrical field modified by diffraction.

*21 **Consecutive generation form**: A form which allows the same individuals to exist in both parent and child generations.

*22 **Parameter study**: A type of study which searches for optimum parameter values by changing parameter values and comparing the results.

Japanese).
[4] N. Chiba and K. Muraoka: "Introduction to ray-tracing Computer Graphics, Chapter 3," Science Inc, 1991 (In Japanese).
[5] M. Mitchell: "An Introduction to Genetic Algorithms," Tokyo Denki University Press, 1997 (In Japanese).
[6] T. Imai: "Estimation model for received levels of incident waves using geometrical optics," IEICE Transactions (B), Vol. J89-B, No. 4, pp. 560-575, Apr. 2006 (In Japanese).
[7] T. Imai et al: "A Propagation Prediction System for Urban Area macrocells using Ray-tracing Methods," NTT DoCoMo Technical Journal, Vol. 6, No. 1, pp. 41-51, Jun. 2004.