Allocation of Base Stations Based on PSO method in Case of Inhomogeneous Communication Distance

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Abstract

This paper is concerned with an algorithm for the allocation of base station in case of inhomogeneous cellular environment. The proposed algorithm is based on the particle swarm optimization (PSO), and we show a triangular cells generated for an artificial communication distance function.

Key words: PSO, inhomogeneous communication distance, 1-ray model, 2-ray model, cellular phone

1. Introduction

Recently, we have proposed an algorithm to generate inhomogeneous two-dimensional (2D) random rough surface (RRS) by modifying the convolution method for generating homogeneous RRS [1], [2]. In case of homogeneous RRS, electromagnetic wave propagations can be well characterized in terms of amplitude modification factor α and propagation order of distance β which were first introduced by Hata [3], and consequently we can estimate communication distance with these parameters [4].

Contrary to the homogeneous case, the above mentioned two parameters α and β might be varied from point to point, since the root mean square of height h and correlation length $c\ell$ of the inhomogeneous RRS changes from one area to another. As a result, communication distance might also be changed from point to point resulting in the case of inhomogeneous communication distance [5].

Propagation in the urban, suburban and open areas shows similar characteristics as was described by the empirical equations for the electromagnetic wave propagation in these areas [3]. According to the empirical equations, the propagation order of distance β is dependent only on the height of a base station antenna, and the amplitude modification factor α is strongly dependent on the density of buildings or houses of the urban or suburban city.

In this paper, we first discuss communication distance function based on 1-ray and 2-rays models of electromagnetic wave propagation in urban areas or along RRSs. Second, we apply the particle swarm optimization (PSO) algorithm [6] to allocation of base stations (BSs) in case of inhomogeneous cellular environment or allocation of sensor network nodes distributed on an inhomogeneous RRS. Finally, we show a numerical example of triangular cells generated for an artificial communication distance function.

2. Field estimation

We can approximate the electric field distributions in the urban or along RRS by using amplitude modification factor α and order of propagation distance β with 1-ray or 2-rays model. The results are summarized in the far zone ($r >> \lambda$) as follows:

$$\boldsymbol{E_1}(\alpha,\beta) = 10^{\alpha/20}10^{(\beta-1)\Gamma/20}r^{(1-\beta)}\boldsymbol{E_i}\ , \quad \boldsymbol{E_2}(\alpha,\beta) = 10^{\alpha/20}10^{(\beta-2)\Gamma/20}r^{(2-\beta)}\boldsymbol{E_t}\ . \tag{1}$$

The incident field of 1-ray model and the total field of 2-rays model are given by

$$\boldsymbol{E_i} = \sqrt{30G_sP_s}\sin\theta\frac{e^{-j\kappa_0 r}}{r}\boldsymbol{\Theta}^{\nu}(\boldsymbol{r},\boldsymbol{p_s})\ , \quad \boldsymbol{E_t} = \boldsymbol{E_i} + \sqrt{30G_sP_s}\sin\theta_0\frac{e^{-j\kappa_0 r_0}}{r_0}\boldsymbol{e_r} \tag{2}$$

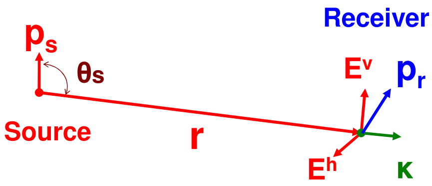

Figure 1: Antenna polarizations $\boldsymbol{p_s}$ and $\boldsymbol{p_r}$, distant vector $\boldsymbol{r}$ and vertical and horizontal electric fields $\boldsymbol{E^v}$ and $\boldsymbol{E^h}$.

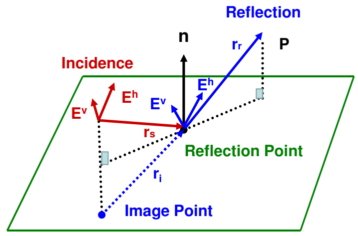

Figure 2: Reflection from a ground plane.

where the time dependence $e^{j\omega t}$ is assumed with $\kappa_0 = \lambda/2\pi$. Moreover, $\boldsymbol{r}$ is the position vector from source to receiver as shown in Figure 1, and the reflected electric field vector is given by

$$\boldsymbol{e_r} = R^v(\theta_i)[\boldsymbol{\Theta}^v(\boldsymbol{r_s}, \boldsymbol{p_s}) \cdot \boldsymbol{\Theta}^v(\boldsymbol{r_r}, \boldsymbol{n})]\boldsymbol{\Theta}^v(\boldsymbol{r_r}, \boldsymbol{n})] \quad + R^h(\theta_i)[\boldsymbol{\Theta}^h(\boldsymbol{r_s}, \boldsymbol{p_s}) \cdot \boldsymbol{\Theta}^h(\boldsymbol{r_r}, \boldsymbol{n})]\boldsymbol{\Theta}^h(\boldsymbol{r_r}, \boldsymbol{n})] \tag{3}$$

where $r_0 = r_s + r_r$ and r_s is the distance from a source to a reflection point and r_r is the distance from the reflection point to a receiver as shown in Figure 2. The vertical and horizontal unit vectors are computed by

$$\boldsymbol{\Theta}^v(\boldsymbol{r}, \boldsymbol{p_s}) = \frac{[(\boldsymbol{r} \times \boldsymbol{p_s}) \times \boldsymbol{r}]}{|(\boldsymbol{r} \times \boldsymbol{p_s}) \times \boldsymbol{r}|}\ , \qquad \boldsymbol{\Theta}^h(\boldsymbol{r}, \boldsymbol{p_s}) = \frac{(\boldsymbol{r} \times \boldsymbol{p_s})}{|\boldsymbol{r} \times \boldsymbol{p_s}|}\ . \tag{4}$$

The Fresnel reflection coefficients are given for vertical and horizontal electric components as follows:

$$R^h(\theta_i) = \frac{\cos\theta_i - \sqrt{\epsilon_c - \sin^2\theta_i}}{\cos\theta_i + \sqrt{\epsilon_c - \sin^2\theta_i}}\ , \quad R^v(\theta_i) = \frac{\epsilon_c\cos\theta_i - \sqrt{\epsilon_c - \sin^2\theta_i}}{\epsilon_c\cos\theta_i + \sqrt{\epsilon_c - \sin^2\theta_i}} \tag{5}$$

where $\epsilon_c = \epsilon_r - j\sigma/\omega\epsilon_0$ is the complex permittivity of the ground plane with dielectric constant ϵ_r and conductivity σ. The directivity of the source antenna and the incident angle at the reflection point are given by

$$\sin\theta = \frac{|\boldsymbol{p_s} \times \boldsymbol{r}|}{r}\ , \quad \sin\theta_0 = \frac{|\boldsymbol{p_s} \times \boldsymbol{r_s}|}{r_s}\ , \quad \sin\theta_i = \frac{|\boldsymbol{n} \times \boldsymbol{r_s}|}{r_s}\ . \tag{6}$$

The field matching factor Γ used in Eq.(1) is calculated by using Eq.(2) as follows:

$$\Gamma = 20\log_{10}(r|\boldsymbol{E_t}|/|\boldsymbol{E_i}|)\ \ [dB] \quad (r >> \lambda)\ . \tag{7}$$

Consequently, with the unit vector $\boldsymbol{p_r}$ of the receiving antenna as shown in Figure 1, the received power of the small dipole antenna can be expressed as [7]

$$P_r = \frac{\lambda^2 G_r}{4\pi} \cdot \frac{|\boldsymbol{E} \cdot \boldsymbol{p_r}|^2}{Z_0}\ \ [W] \tag{8}$$

where $G_r = 1.5$ is the gain of the receiving small dipole antenna and the intrinsic impedance of the free space is given by $Z_0 = \sqrt{\mu_0/\epsilon_0} \simeq 120\pi\ [\Omega]$.

3. Communication distance and communication distance function

Combining Eq.(1) and Eq.(2) leads to the electric field intensity of the 1-ray model as follows:

$$|\boldsymbol{E_1}| = 10^{\frac{\alpha}{20}} \cdot 10^{\frac{(\beta-1)\Gamma}{20}} \cdot \frac{\sqrt{30 G_s P_s}}{r^\beta} \tag{9}$$

where the antenna orientation is assumed to be arranged so that the maximum received power may be obtained. Let E^{min} and P_r^{min} be the minimum detectable electric field intensity and received power, respectively. Then we have the following form of communication distances:

$$r_c = 10^{\frac{\alpha}{20\beta}} \cdot 10^{\frac{(\beta-1)\Gamma}{20\beta}} \cdot \left(\frac{\sqrt{30 G_s P_s}}{E^{min}} \right)^{\frac{1}{\beta}} \quad , \quad r_c = 10^{\frac{\alpha}{20\beta}} \cdot 10^{\frac{(\beta-1)\Gamma}{20\beta}} \cdot \left(\frac{30\lambda^2}{4\pi Z_0} \cdot \frac{G_s G_r P_s}{P_r^{min}} \right)^{\frac{1}{2\beta}} \tag{10}$$

As described earlier, order of propagation distance β is almost constant when the source antenna height is fixed, and Γ is also almost constant when the receive point is far from the source antenna. As a result, the communication distance r_c is mainly dependent on the amplitude modification factor α. While the communication distance is isotropic for a homogeneous RRS, it might be anisotropic in the urban and suburban area. So, considering the azimuthal dependence of communication distance, we propose a communication distance function by taking average with respect to azimuthal angle as follows:

$$\Phi(r) = \frac{1}{2\pi} \int_0^{2\pi} r_c d\phi \; . \tag{11}$$

It is evident from the Hata's empirical equations [3] that the value of the communication distance function is small in the urban area, but it is large in the open area.

4. Generation of inhomogeneous triangular cells based on PSO

Let a communication distant function be $\Phi(\boldsymbol{r})$ which expresses the coummunication distance averaged in all directions at a point $\boldsymbol{r}$. Based on this function, we can estimate the communicatable length between $\boldsymbol{r_1}$ and $\boldsymbol{r_2}$. Considering the reciprocity theorem of electromagnetic field, we propose here three types of communicatable length as follows:

$$D(\boldsymbol{r}_1, \boldsymbol{r}_2) = \begin{cases} [\Phi(\boldsymbol{r}_1) + \Phi(\boldsymbol{r}_2)]/2 & \text{(Type 1)} \\ \sqrt{\Phi(\boldsymbol{r}_1)\Phi(\boldsymbol{r}_2)} & \text{(Type 2)} \\ \min\{\Phi(\boldsymbol{r}_1), \Phi(\boldsymbol{r}_2)\} & \text{(Type 3)} \; . \end{cases} \tag{12}$$

The first one is an arithmetical mean, the second one is a geometric mean, and the last one has the most critical measure for communicatable length. In the following numerical examples we use the second type. Then we introduce the ratio of the communicatable length to its realistic length as follows:

$$D_r(\boldsymbol{r}_1, \boldsymbol{r}_2) = |\boldsymbol{r}_1 - \boldsymbol{r}_2| / D(\boldsymbol{r}_1, \boldsymbol{r}_2) \; . \tag{13}$$

It is evident that communication between $\boldsymbol{r}_1$ and $\boldsymbol{r}_2$ is possible if $D_r(\boldsymbol{r}_1, \boldsymbol{r}_2) \leqq 1$, while it is impossible otherwise.

Now we consider the allocation of base stations in an inhomogeneous communication environment. This problem is considered to be an optimization problem with a constraint condition. The constraint condition is escribed as each triangle should be composed of three edges with communicatable length, and the optimization is described as the area spanned by each triangle should be as large as possible. In order to solve the present problem, we apply the PSO method [6], since it is simply applicable to the complicated inhomogeneous constraint condition. To show the effectiveness of PSO, we consider an artificial communication distance function with three minimum peaks defined by

$$\begin{aligned} \Phi(\boldsymbol{r}) = \Bigg[& 1 - \delta \exp\Big(-\frac{(x-3L)^2}{4L^2} - \frac{(y+1.5\sqrt{3}L)^2}{4L^2}\Big) - \delta \exp\Big(-\frac{(x+3L)^2}{4L^2} - \frac{(y+1.5\sqrt{3}L)^2}{4L^2}\Big) \\ & - \delta \exp\Big(\frac{(y-1.5\sqrt{3}L)^2}{4L^2}\Big) \Bigg] \end{aligned} \tag{14}$$

where L is a unit length corresponding to a communication distance in the free space and δ is a parameter indicating inhomogeneity of the communication environment. Figure 3 shows the numerical example of Eq.(14) when $\delta = 0.5$.

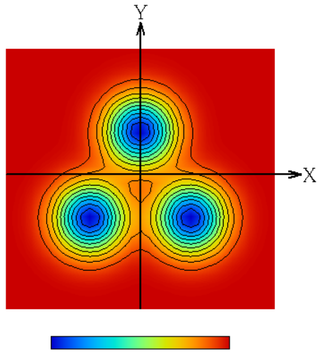

Figure 3: An example of communication distance function with $\delta = 0.5$ in Eq.(14).

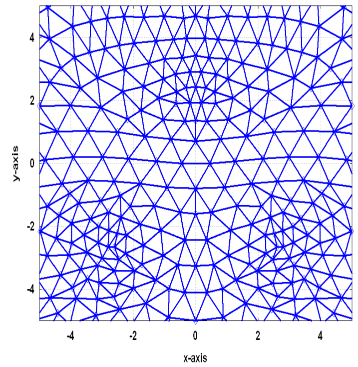

Figure 4: An example of communication distance function with $\delta = 0.5$ in Eq.(14).

Figure 4 shows an example of triangular cells corresponding to the inhomogeneous communication distance function with $\delta = 0.5$ in Eq.(14). All cells are composed of triangles with different geometries, and cell meshes are dense in the region where communication distance function is relatively small as given by Eq.(14). Contrary to the homogeneous case, all cells cannot be generated only by the PSO algorithm for triangle generation, and therefore, the total area spanned by these cells is not optimal.

5. Conclusion

First, we have reviewed 1-ray and 2-rays propagation models to introduce an communication distance function for propagation characteristics in the urban area or along RRS. Second, we have introduced the communicatable length, and it has been shown that the allocation of BSs is reduced to an optimization problem with a constraint condition. Finally, the particle swarm optimization (PSO) method has been applied to the allocation problem, and we have shown a numerical example of the inhomogeneous triangular cells by using an artificial communication distance function with three peaks.

We have to investigate the handover simulation of mobile stations (MSs) when they walk randomly around in the inhomogeneous triangular cells presented here. This study deserves as a future work.

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