Urban Area Propagation Path Loss Reduction by Dynamic Differential Evolution Algorithm

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Abstract — In the wireless outdoor communication, the buildings in modern cities to make the outdoor communication more difficult. In this paper, we propose the shooting and bouncing ray/image (SBR/Image) method to compute the path loss for outdoor environments in the commercial area of New Taipei. Three types of antenna arrays such as L shape, Y shape, and circular shape arrays are considered. Moreover, dynamic differential evolution algorithm (DDE) is employed to optimize the excitation voltages and phases for these antenna arrays to reduce the path loss and compare with the genetic algorithm (GA). The GA and DDE optimization is applied to a high order nonlinear optimization problem. By the obtained antenna patterns, we can find the route with the lowest path loss; meanwhile, transmission power using this route in the base station can be reduced. Numerical results show that the performance in reduction of path loss. The DDE algorithm outperforms the GA for proposed antenna arrays. The investigated results can improve design of outdoor communication system.

Keywords —SBR/Image method, outdoor environments, DDE, antenna patterns, path loss.

I. INTRODUCTION

Radio signal propagation modeling plays an important role in designing wireless communication systems. In the wireless outdoor communication, the heights of buildings are tall in modern cities to make the outdoor communication more difficult and complex. Obstructions by the buildings in outdoor environments will reduce the received power and increase received data error rate. The base station and their corresponding path loss on several routes in the outdoor environment can be calculated [1]-[3]. Different algorithms to predict the affection of obstruction are presented in many literatures [4]-[6]. For most papers, omni-directional dipoles are used for receivers and antenna arrays are employed for transmitters [7].

Consequently, varying different structures of antenna arrays to achieve good directivity is necessary. Applying GA to reduce signal path loss in outdoor communication has been presented as in [4]. Compared to GA, DDE is much easier to implement and converge faster [8]. In this paper, three different types of antenna arrays are investigated. To synthesize antenna pattern for the lowest path loss [9]-[13], the excitation problems are reformulated as optimization problems. GA and DDE are used to reduce the path loss in the outdoor environment.

In Section II describes the pattern synthesis by the algorithms. The simulating environment and the design of the proposed arrays are also described. In Section III shows the numerical results. Finally, some conclusions are drawn in Section. IV.

II. ANTENNA PATTERN SYNTHESIZED BY THE DYNAMIC DIFFERENTIAL EVOLUTION ALGORITHM

N dipole elements excited by a voltage source are used to form an antenna array. Let V_m and ϕ_m be the amplitude and phase of excitation voltage of the m-th element respectively. Then the total current distribution of N antennas can be calculated by the following equation [14].

$$\sum_{n=1}^{N}\int_{0}^{\ell_n} I_n(z')\left[K_{mn}(z,z')+K_{mn}(z,-z')\right]dz=-\frac{j4\pi}{\eta_0}\left[c_m\cos\phi_m+\frac{V_m}{2}\sin\phi_m\right]$$

$$0\le z\le \ell_m \quad m=1,2,\ldots,N \tag{1}$$

$$K_{mn}(z,z')=\frac{e^{-jkR_{mn}(z,z')}}{R_{mn}(z,z')} \tag{2}$$

I_n and ℓ_n are the current and the length of the n-th element, respectively. η_0 is the free-space impedance. $R_{mn}(z,z')$ is the distance between the point z on the surface of the m-th element and the point z' on the axis of n-th element. c_m is undefined coefficient which can be calculated by the boundary condition of $I_1(\ell_1) = I_2(\ell_2) = \ldots = I_n(\ell_n) = 0$.

For numerical calculation of the problem, the antenna is first divided into sufficient small segments so that current distribution of the antenna over each segment can be considered constant. The moment method is used to solve the current distribution I(z') by equation (1) with a pulse basis function for expanding and the Dirac delta function for testing. Once the current distributions of N dipoles are obtained, the radiation pattern can be computed accordingly.

Next we use the SBR/Image method to calculate the path loss for any antenna pattern. The SBR/Image method can deal with radio wave propagation. It conceptually assumes that many ray tubes are shot from the transmitting antenna and each ray tube bouncing and penetrating in the environments is traced. If the receiving antenna is within a ray tube, the ray tube will contribute to the received field and the corresponding equivalent source (image) can be determined. In addition, the single diffraction is also included in our simulation. The path loss is calculated by the SBR/Image method. The DDE is used to find the optimal excitation voltages to minimize the path loss. It can be observed that the DDE outperforms the differential evolution algorithm when applied to solve a electromagnetic inverse scattering problem [15].

The flow chart for the simulation is shown in Fig. 1. The exciting sources are randomly produced by algorithms and their corresponding antenna pattern can be determined by solving integral equation. Then, the SBR/Image method is used to calculate the path loss with two algorithms in the outdoor environment.

Finally, we adjust the antenna pattern in order to minimize the path loss. In the synthesis procedure, the DDE algorithm is used to minimize the cost function by equation (3). The cost function for the problem is non-smooth and discontinuous with respect to the antenna pattern. It is difficult to solve by gradient methods, since the derivatives is hard to derive.

$$\textbf{Cost Function = Path Loss} \tag{3}$$

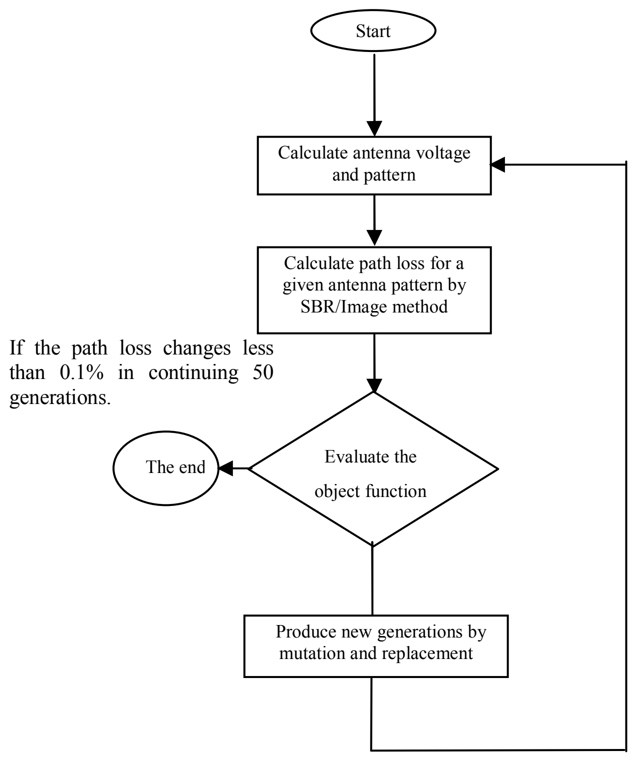

Fig.1. The flow chart for the simulation

III. NUMERICAL RESULTS

The housing of the commercial area on Yinzhuan road in New Taipei city is shown Fig. 2. There are six buildings from A to F in this area. The heights of each building in alphabetical order are 45, 50, 30, 35, 20 and 30 m. The height of the thickness of the walls in these building is 30 cm. The relative dielectric constant and the conductivity of buildings and the ground are assumed to be 8 and 0.0075 s/m, and 15 and 0.012 s/m, respectively.

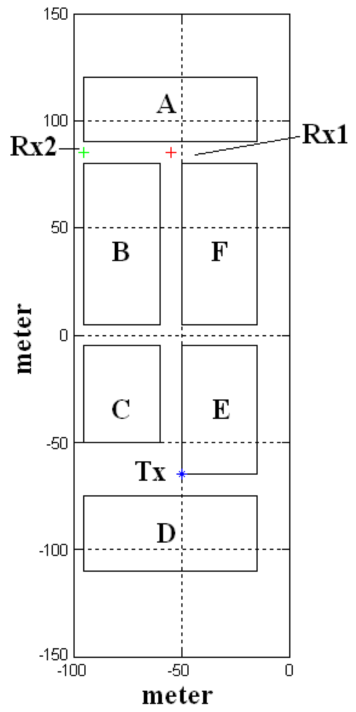

Fig. 2. The simplified layout geometry for simulation

The L shape, Y shape, and circular arrays consisted of 8 short dipoles are used for transmitting antenna arrays. Each element is apart along five centimeter which is corresponding to the half wavelength of 1.9 GHz. The proposed antenna arrays are put on the top of building E at (-50, -65) m. The receiving antenna is a single short dipole antenna with the height of 2m. The searching ranges of excitation voltage and phase are 0~1 volt and 0~360 degrees. The simulated operation frequency is 1.9GHz [12], [16]. The algorithms are applied on a sample environment which is fully modeled with the SBR/Image method. Two basic environments, namely LOS and NLOS, are considered in the followings:

A. LOS case

In this case, the Rx1 is chosen at (-55, 85) m. The path loss with and without using algorithms are given in Table I. There is no obstruction between transmitter and receiver, so path loss in this case are low. In Table I, it is observed that path losses of L shape, Y shape and circular arrays by GA is lower 2.2, 8.2, and 2 dB respectively than the case without the algorithm.

The path losses by DDE algorithm is lower 3.8, 9.2 and 3.5 dB than the case without the algorithm for L shape, Y shape and circular arrays, respectively. It is also clear that path losses reduced by DDE are better than those by GA.

It is also found that the Y shape array has the lowest path loss and the L shape array is the second lowest in path loss. In general, the Y shape array is a good choice for LOS outdoor environments. Fig. 3 show the Y shape array radiation pattern with DDE. It is seen the pattern is more directional to the receiver by the algorithms.

TABLE I .COMPARISON OF PATH LOSS WITH AND WITHOUT ALGORITHM (LOS CASE)

Algorithm	**Antenna arrays**		
	L shape	***Y shape***	***Circular shape***
Without Algorithm	80.0	77.7	83.3
GA	77.8	69.5	81.3
DDE	76.2	68.6	79.8

a. *Path loss (dB)*

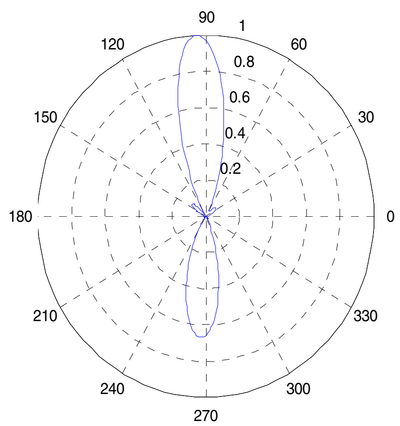

Fig. 3. Radiation pattern of Y array by the DDE algorithm (LOS case)

B. NLOS case

In this case, we set the Rx2 at (-95, 85) m. There are some obstructions between the transmitter and receiver. Similarly, the path loss with GA , DDE and without algorithms are shown in Table II. It is observed that path losses of L shape, Y shape and circular arrays by GA is lower 7, 6, and 3.1 dB than the case without the algorithm, respectively. DDE algorithm is lower 7.8, 7, 3.2 dB than the case without the algorithm for L shape, Y shape and circular arrays respectively. It is also found that path losses reduced by DDE are better than those by GA. It is clear that the path loss by the DDE algorithm is better than those by GA. It is also seen that the L shape array has the lowest path loss. The L shape array radiation pattern with algorithm is shown in Fig. 4.

In the NLOS case, the transmitting signal can't reach the receiver directly. Nevertheless, it is seen that antenna patterns by algorithms can find the route with the lowest path loss by reflection mechanism. This route avoids the obstructions between the transmitter and receiver, and also shows the direction with fewer obstructions.

TABLE II. COMPARISON OF PATH LOSS WITH AND WITHOUT ALGORITHM (NLOS CASE)

Algorithm	**Antenna arrays**		
	L shape	***Y shape***	***Circular shape***
Without Algorithm	104.8	109.9	108.2
GA	97.8	103.9	105.1
DDE	97.0	102.9	105.0

a. *Path loss (dB)*

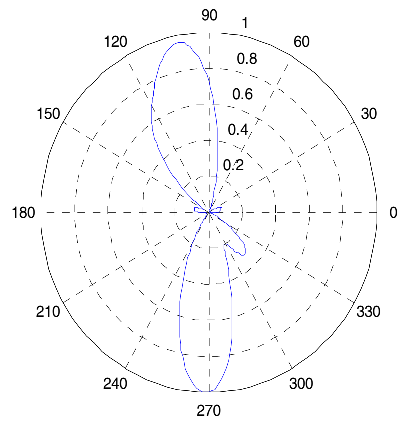

Fig. 4. Radiation pattern of L array by the DDE algorithm (NLOS case)

IV. CONCLUSIONS

Three different antenna arrays for reducing the path loss in outdoor wireless communication channel by the GA and DDE algorithm are presented. The main advantage of our research is that the implementation of the SBR/image and the algorithms can be carried out in the same software, which is herein Fortran. By using SBR/Image method to compute the path loss. Based on the path loss, the synthesis problem can be reformulated into an optimization problem. GA and DDE algorithms are employed to minimize the cost function (path loss). The GA and DDE are used to regulate the antenna excitation voltages and phases of each array element to minimize the path loss. Numerical results show that path loss in LOS and NLOS cases can be reduced about 2~9.2 dB and 3.1~7.8 dB and main beam orientated towards desired user direction, respectively. It is also found that the path loss reduction the DDE outperforms the GA.

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