Novel Radiation Pattern by Genetic Algorithms in Wireless Communication

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Abstract

The genetic algorithm is used to synthesize the radiation pattern of the directional circular arc array to minimize the bit error rate (BER) performance in indoor wireless communication system. By using the impulse response of multipath channel, the performance of the synthesized antenna pattern on BPSK (binary phase shift keying) system with phase and timing recovery circuits can be calculated. Based on the topography of the antenna and the BER formula, the synthesis problem can be reformulated into an optimization problem and solved by the genetic algorithm. Numerical results show that the synthesized antenna pattern is effective to combat the multipath fading and can increase the transmission rate of indoor millimeter wave system.

I. Introduction

Wireless local loop networks have attracted considerable attention in recent years. However, the severe multipath fadings, which are characteristics of the indoor radio channels, limit the data rate [1] - [3]. Applying appropriately narrow antenna beams can overcome this degradation [4], [5]. To synthesize the antenna pattern to minimize the BER performance, the excitation problems are reformulated as optimization problems. The genetic algorithm is a well-known algorithm, which uses random choice to search through a coding of a parameter space and find the global extreme of the problem. Most papers apply genetic algorithm for searching minimum sidelobe level of the antenna pattern [6]. However, this pattern cannot guarantee to obtain minimum BER performance of the communication system.

In this paper, the genetic algorithm is used to synthesize the antenna pattern to minimize the BER performance in indoor millimeter-wave transmission over a typical room. Section II describes channel modeling and system description. The pattern synthesis by the genetic algorithm is given in section III. Section IV shows the numerical results. Finally, some conclusions are drawn in Section V.

II. Channel Modeling and System Description

(A) Calculation of the channel characteristics

The equation used to model the multipath radio channel is a linear filter with an equivalent baseband impulse response given by

$$h_b(\tau)=\sum_{K=0}^{N}\beta_k e^{i\theta_k}\delta(\tau-\tau_k) \qquad (1)$$

where k is the path index, β_k is the path gain, θ_K is the phase shift and τ_K is the time delay of the kth path. $\delta(\ )$ is the Dirac delta function.

The impulse response function for a given antenna pattern at any transmitter-receiver location is computed by modified shooting and bouncing ray/image (SBR/Image) techniques [7]. The SBR/Image method can deal with high frequency radio wave propagation in complex indoor environments.

(B) System block diagram

A BPSK (binary phase shift keying) system with raised cosine pulse shaping (rolloff factor α), phase and timing recovery circuits is considered. The equivalent baseband channel models are plotted in Fig. 1. The probability of error for this BPSK system is given by [8]

$$P_e = \sum_n p\{a_n\} \cdot \frac{1}{2} erfc\left[\frac{\sum_n a_n \operatorname{Re}\{[h_t(t_s - nT) \otimes h_b(t_s - nT) \otimes h_r(t)] \cdot e^{-j\phi}\}}{\sigma_n}\right] \tag{2}$$

where σ_n is the standard deviation of the additive noise and $erfc(x) = \frac{2}{\sqrt{\pi}} \int_x^{\infty} e^{-y^2} dy$. Note that the error probability P_e in equation (2) which is related to $h_b(t)$ will be affected by the antenna pattern used.

III. Pattern Synthesis of Arc Array by the Genetic Algorithm

Circular arrays have a number of well-known advantages over linear arrays, because of their symmetry. This property also carries over to arc arrays in which a small segment of the circular array is used to form the beam, and steering of the beam is now achieved by appropriately selecting a segment or arc and weighting the element signals independently of the chosen segment. They are capable of giving nearly as good performance as circular arrays (of the same radius), and thus yielding considerable saving in hardware/signal processing.

The pattern synthesis procedure using the genetic algorithm to find the minimum BER performance begins with an array of fixed geometry with a set of starting excitations. The excitations are then changed until the minimum error probability is achieved. We assume an array of M directional elements with equal space situated over an circle of radius R as shown in Fig. 2. The angular spacing between consecutive elements is $2\pi / M$. An arc region of L element is "turned on" and is used to synthesize the desired pattern, which will minimize the error probability.

The genetic algorithm is a search algorithm based on the mechanics of natural selection and natural genetics. They find the global maximum of an objective function (or fitness function) of the problem by random search. In this case, both parameters are I_n and α_n. Then three operators - reproduction, crossover and mutation – are employed to search the optimization of the problem through a coding of a parameter space. The flow chart for the genetic algorithm is shown in Fig. 3.

In the synthesis procedure, the genetic algorithm is used to maximize the following object function to find the optimal antenna pattern:

$$SF = \left(\sum_i P_{e,i} \right)^{-1} \tag{3}$$

Here $P_{e,i}$ is the error probability for ith point. Note that the relationship of the antenna pattern and the error probability $P_{e,i}$ cannot be formulated by simple equation. In fact, the antenna pattern will affect the impulse response h_b in equation (1). As a result, it affects the error probability $P_{e,i}$ in equation (2). The strong point of the genetic algorithm is that it can find out the solution even if the performance index cannot be formulated by simple equation. In our simulation, as soon as the object function (SF) changes by less than 1% in two successive generations, the algorithm will be terminated and a solution is then obtained.

IV. Numerical Results

To synthesize the optimal antenna pattern, circular array located on xy plane with radius $R = 2.392\lambda$ and $M = 30$ was considered. The spacing of elements on the arc is $\lambda/2$. Here λ is the wavelength. Next, let us consider a typical room as shown in Fig. 4. In this room, assume that the 25cm-thick walls, floor and ceiling are all concrete materials with a complex dielectric constant $\varepsilon_r = 6.5 - 0.43j$ at 57.5GHz [1], [9]. The transmitting antenna is a half-wave dipole and vertically polarized. It is located at the center of the room with coordinates (5.5m, 6m, 3.5m). The height of the receiving antenna is 1.5 meters. The excitation currents are computed by using the genetic algorithm via Eq. (3). The length of coding is set to be 16 bits (i.e., Q=16 bits). In other words, the bit number of a chromosome is 480 ($2\times15\times16$). The search range for the amplitude is chose from 0 to 1. Besides, the search range for the phase is from 0 to 2π. Population size is chosen as 1000. The mutation probability is set to be 1%.

The impulse response of the room for any antenna pattern was calculated at 57.5 GHz by SBR/Image method. The number of ray tubes shooting from the transmitter is 200,000. The maximum number of bounces setting beforehand is five, and the convergence is confirmed. Since the extra attenuation at 57.5 GHz due to atmospheric absorption and scattering in negligible over small distance, the atmospheric attenuation is not considered in the simulation [2].

With all these parameters, the synthesis pattern by the genetic algorithm is shown in Fig. 5. The final BERs for multiple points are less than 10^{-7}. It is clear the multipath is reduced by the optimal antenna. Comparing with the BER for omnidirection antenna is 10^{-3}, it is seen the BER reduced a lot. Many similar realizations have been done and it is found that the multipath effect is reduced by the optimal antenna and method for is very useful for wireless communication system.

V. Conclusions

Synthesizing optimal antenna pattern to minimize the BER performance in indoor wireless local loop is presented. The impulse response of the millimeter wave channel is computed by SBR/Image. By using the impulse response of the multipath channel and the synthesized antenna pattern, the BER performance of BPSK communication system is investigated. Based on the BER formulation, the synthesis problem can be reformulated into an optimization problem. In our approach, the object is defined as the inversion of BER instead of sidelobe level of the antenna. Numerical results show that the BER can be reduced a lot compared to the omnidirectional antenna in indoor wireless millimeter wave channel.

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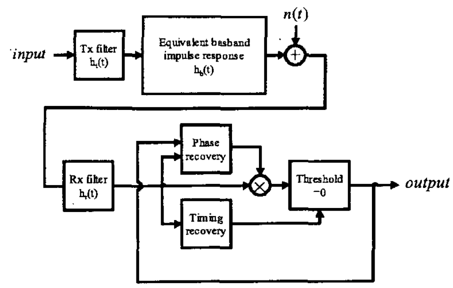

Fig. 1

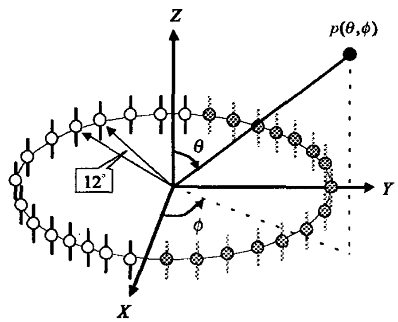

Fig. 2

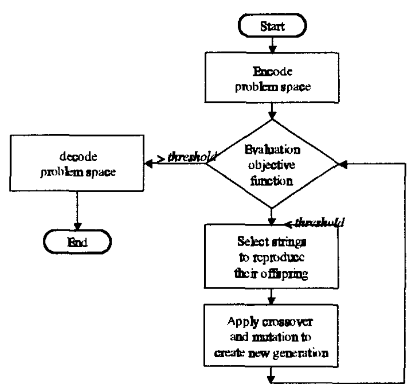

Fig. 3

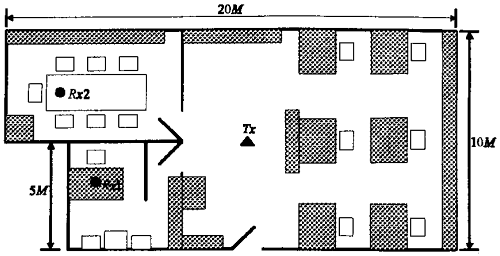
20M
Rx2
Tx
10M
5M
Rx1

Fig. 4

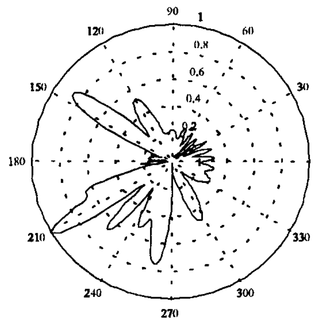
90
1
60
120
0.8
0.6
30
150
0.4
0.2
180
0
210
330
240
300
270

Fig. 5