Comparison of Different UWB Antenna Arrays

Chien-Hung Chen
Department of Computer and Engineering
Taipei College of Maritime Technology
Shilin, Taipei, Taiwan, R.O.C.
f1092@mail.tcmt.edu.tw

Min-Hui Ho
Department of Electrical Engineering
Tamkang University
Tamsui, Taipei, Taiwan, R.O.C.
nancy_2002_168@yahoo.com.tw

Chien-Ching Chiu
Department of Electrical Engineering
Tamkang University
Tamsui, Taipei, Taiwan, R.O.C.
chiu@ee.tku.edu.tw

Shu-Han Liao
Department of Electrical Engineering
Tamkang University
Tamsui, Taipei, Taiwan, R.O.C.
shliao@ee.tku.edu.tw

***Abstract*—In this paper, we use three types of antenna arrays such as L shape, Y shape, and circular shape arrays are used in the transmitter and their corresponding bit error rate (BER) on several paths in the indoor environment are calculated. Based on the topography of the antenna array and the BER formula, the array pattern synthesis problem can be reformulated into an optimization problem and solved by the particle swarm optimizer algorithm (PSO). Numerical results show that the synthesized antenna array pattern is effective to focus maximum gain to the line of site (LOS) path for three antenna arrays. The synthesized array pattern also can mitigate severe multipath fading in complex propagation environment.**

Keywords-PSO; BER; antenna array

I. INTRODUCTION

Ultra wideband (UWB) signal is defined as a signal having fractional bandwidth greater than 20% of the center frequency [1]. In the past, most papers apply genetic algorithms for searching the minimum sidelobe level of the antenna [2]-[6]. In [7], desired phase weights determined by the scan angle and array geometry, the amplitude weights of elements are optimized by differential evolution algorithm to drive down the side-lobes. However, this pattern cannot guarantee to obtain the minimum BER performance.

PSO is a new technology in evolution computing. The method was originally proposed by J. Kenney and R. Eberhart as an optimization method in 1995 [8]. In this paper, we propose a smart ultra wideband antenna array at the transmitter to synthesize an array pattern for minimizing the BER performance in a UWB communication system. We use the PSO to regulate the antenna feed length of each array element to minimize the BER performance. Consequently, varying different structures of antenna arrays to achieve good directivity is necessary. Three different types of antenna arrays are investigated. To synthesize antenna pattern for the lowest BER, the excitation problems are reformulated as optimization problems. PSO is used to reduce the BER in the indoor environment.

The remaining sections of this paper are organized as follows: section II briefly explains the formulation of the problem which includes antenna pattern, channel modeling and the BER calculation. Section III describes the particle swarm optimizer. The numerical results are then presented in section IV. The simulating environment and the design of the proposed arrays are also described. The conclusion is made in section V.

II. SYSTEN DESCRIPTION

A. Array Pattern

Three types of antenna arrays such as L shape, Y shape, and circular shape arrays consist of eight UWB dipole antennas are used in the transmitter, as shown in Fig. 1. We consider array of eight UWB printed dipole antennas. The array factor of this antenna array can be written as

$$AF(\theta,\phi,f)=\sum_{n=1}^{N_T-1} F_n \exp\left[-j\left(K\cdot X_n \sin\theta\cos\phi+K\cdot Y_n \sin\theta\sin\phi+\psi_n\right)\right] \quad (1)$$

where θ and ϕ are the spherical coordinate angles from the origin to the viewpoint in the elevation plane and azimuth plane. f is the frequency of a sinusoidal wave. N_T is the element number. $K=2\pi/\lambda$ is the wavenumber, where λ is the wavelength of the sinusoidal wave. ψ_n is the phase delay of the excitation current for the *n*-th element and F_n is the amplitude of excitation current for the *n*-th element. In this paper, we regulate the F_n of each array element to get a optimal radiation pattern which can minimize the BER performance. X_n and Y_n are *x*-coordinate and *y*-coordinate positions of the *n*-th array element respectively. Thus the total radiation vector can be expressed as

$$\vec{N}(\theta,\phi,f)=AF(\theta,\phi,f)\cdot\vec{N}_e(\theta,\phi,f) \quad (2)$$

Where $\vec{N}_e(\theta,\phi,f)$ is the radiation vector of individual element which can be obtained by the HFSS software based on the finite element method [9].

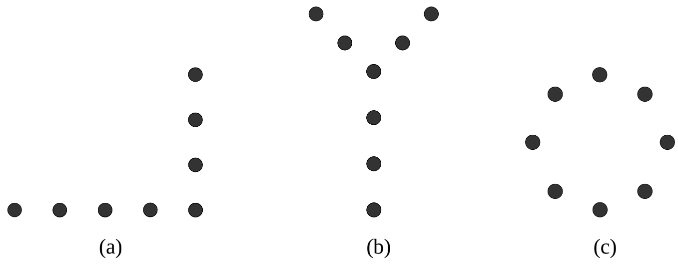

Figure 1. Three different types transmitting antenna arrays consist of eight UWB dipole antennas. (a) L shape (b) Y shape (c) circular shape

B. UWB Channel Modeling

We develop shooting and bouncing ray/image (SBR/Image) techniques including the antenna pattern to model our simulation channel. The channel frequency response can be obtained as following

$$H(f) = \sum_{i=1}^{N_P} a_i(f) e^{j\theta_i(f)} \tag{3}$$

Where f is the frequency of sinusoidal wave, i is the path index, θ_i is the i-th phase shift, a_i is the i-th receiving magnitude which depends on the radiation vector of the transmitting and receiving antenna in (2). Note that the receiving antenna in our simulation is a omnidirectional UWB dipole antenna. On the other hand, the transmitter is the UWB antenna array which has been described in above section. The channel frequency response of UWB can be calculated by equation (3) in the frequency range of UWB.

The frequency response is transformed to the time domain by using the inverse fast Fourier transform with the Hermitian signal processing. Therefore the time domain impulse response of the equivalent baseband can be written as follows:

$$h_b(t) = \sum_{m=1}^{M_T} \alpha_m \delta(t - \tau_m) \tag{4}$$

where M_T is the number of paths. α_m and τ_m are the channel gain and time delay for the m-th path respectively.

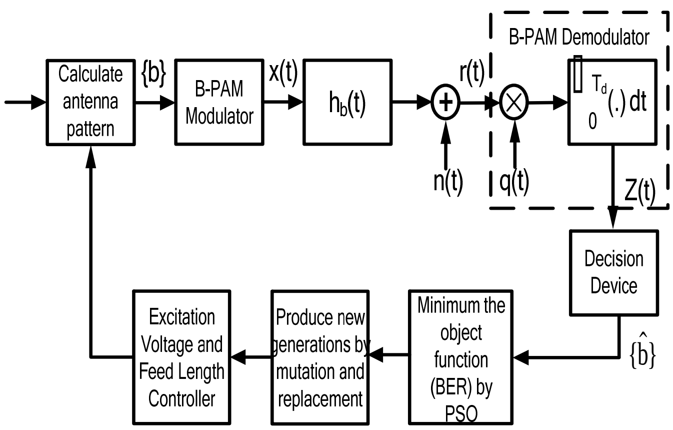

Figure 2. Block diagram of the simulated system

C. Formulation of BER

The SBR/Image method is used to calculate the BER in the indoor environment. PSO is used to find the excitation voltage and feed length to minimize the BER.

As shown in Fig. 2, {b} is the input binary data stream and $\{\hat{b}\}$ is the output binary data stream after demodulator and decision device. When data stream {b} passing through the binary pulse amplitude modulation (B-PAM) modulator, the transmitted UWB pulse stream is expressed as follows:

$$x(t) = \sum_{n=0}^{\infty} p(t - nT_d) d_n \tag{5}$$

where $p(t)$ is the transmitted waveform. $d_n \in \{\pm 1\}$ is a B-PAM symbol and is assumed to be independent identically distributed (i.i.d.). T_d is the duration of the transmitting signal. The transmitted waveform $p(t)$ is the Gaussian waveform with ultra-short duration T_p at the nanosecond scale. Note that T_d is the duration of the transmitting signal and T_p is the pulse duration. The value of T_d is usually much larger than that of T_p. The Gaussian waveform $p(t)$ can be described by the following expression:

$$p(t) = \frac{1}{\sqrt{2\pi}\,\sigma} e^{\frac{-t^2}{2\sigma^2}} \tag{6}$$

where t and σ are time and standard deviation of the Gaussian wave, respectively. The average transmit energy symbol E_t can be expressed as

$$E_t = \int_0^{T_d} p^2(t)dt \tag{7}$$

where E_t is the average transmitted energy.

The received signal $r(t)$ can be expressed as follows:

$$r(t) = \left[x(t) \otimes h_b(t)\right] + n(t) \tag{8}$$

where $x(t)$ is the transmitted signal and $h_b(t)$ is the impulse response of the equivalent baseband, n(t) is the white Gaussian noise with zero mean and variance $N_0/2$. The correlation receiver samples the received signal at the symbol rate and correlates them with suitably delayed references given by

$$q(t) = p[t - \tau_1 - (n-1)T_d] \tag{9}$$

where τ_1 is the delay time of the first wave. The output of the correlator at $t = nT_d$ is

$$Z(n) = \int_{(n-1)T_d}^{nT_d} \left\{ [\sum_{i=0}^{\infty} p(t - iT_d)d_i] \otimes h_b(t) \right\} \cdot q(t)dt + \int_{(n-1)T_d}^{nT_d} n(t)q(t)dt$$
$$= V(n) + \eta(n) \tag{10}$$

It can be shown that the noise components $\eta(n)$ of (10) are uncorrelated Gaussian random variables with zero mean. The variance of the output noise η is

$$\sigma^2 = \frac{N_0}{2} E_t \tag{11}$$

The conditional error probability of the *n*-th bit is thus expressed by:

$$P_e\left[Z(n)\,|\,\bar{d}\right] = \frac{1}{2} erfc\left[\frac{V(n)}{\sqrt{2}\sigma}\cdot(d_n)\right] \tag{12}$$

Where $erfc(x) = \frac{2}{\sqrt{\pi}}\int_x^{\infty} e^{-y^2} dy$ is the complementary error function and $\{\bar{d}\} = \{d_0, d_1, \ldots d_n\}$ is the binary sequence. Note that the average BER for B-PAM impulse radio UWB system can be expressed as [10]

$$BER = \sum_{i=1}^{2^n} P(\bar{d})\cdot\frac{1}{2} erfc\left[\frac{V(i)}{\sqrt{2}\sigma}\cdot(d_n)\right] \tag{13}$$

where $P(\bar{d})$ is the occurring probability of the binary sequence $\bar{d}$.

III. PARTICLE SWARM OPTIMIZER

Particles (potential solutions) are distributed throughout the searching space and their positions and velocities are modified based on social behavior. The social behavior in PSO is a population of particles moving towards the most promising region of the search space. Clerc [11] proposed the constriction factor to adjust the velocity of the particle for obtaining the better convergence, the algorithm was named as constriction factor method.

When analyzing the antenna array, the feed length of each array element provides the phase delay of excitation current which varies with different frequencies. The relationship between the *n*-th antenna feed length ℓ_n and the excitation current phase delay ψ_n can be expressed as follows:

$$\psi_n = \frac{2\pi}{\lambda}\ell_n \tag{14}$$

Where λ is the wavelength. Thus, we regulate the antenna feed length of each array element to get a optimal radiation pattern which can minimize the BER performance. The feed length of each array element can be decoded by the following equation：

$$\ell_n = Q_{\min} + \frac{Q_{\max} - Q_{\min}}{2^M - 1}\sum_{i=0}^{M-1} b_i^{\ell n} 2^i \tag{15}$$

Where $b_0^{\ell n}, b_1^{\ell n}, \cdots, b_{M-1}^{\ell n}$ (genes) are *M*-bit strings of the binary representation of ℓ_n .The $Q_{\min}$ and $Q_{\max}$ are the minimum and the maximum values admissible for ℓ_n, respectively. In practical cases, $Q_{\min}$ and $Q_{\max}$ can be determined by the prior knowledge of the objects.

Finally, we adjust the antenna pattern in order to minimize the BER. In the synthesis procedure, the PSO algorithm is used to minimize the following cost function (CF):

$$\mathrm{CF} = \sum_{i=1}^{2^n} P(\bar{d})\cdot\frac{1}{2} erfc\left[\frac{V(i)}{\sqrt{2}\sigma}\cdot(d_n)\right] \tag{16}$$

Where CF is the average BER for B-PAM impulse radio UWB system. PSO is used to search the excitation voltage and feed length to minimize the BER of the communication system.

IV. NUMERICAL RESULTS

Fig. 3 is the Microwave laboratory in Tamkang University and laboratory has dimensions of 9.2m (Length) × 10m (Width) × 3m (Height). The transmitting antenna Tx and receiver Rx were all mounted 1.7 meter above the floor. The transmitting and receiving antennas are UWB antennas. Tx and Rx are at a distance of approximately 2.3 meter.

A three-dimensional SBR/Image technique combined antenna radiation pattern has been presented in this paper. This technique is used to calculate the UWB channel impulse response for each location of the receiver. We use the impulse response to calculate the BER. The frequency range for the UWB channel is simulated from 3GHz to 6GHz, since the array element has the omnidirectional characteristic in this frequency range [12]. The operation frequency is 3~6 GHz. LOS case is considered in the followings:

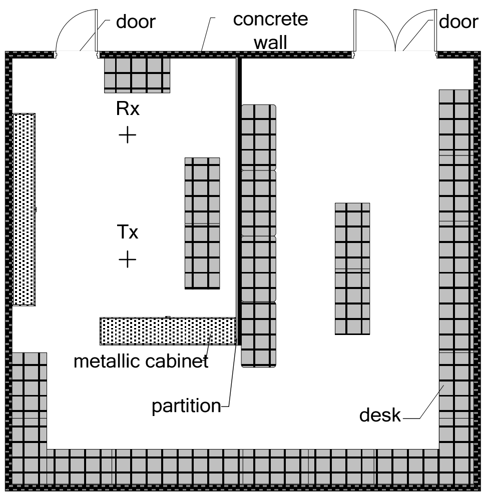

Figure 3. A plan view of the simulated environment

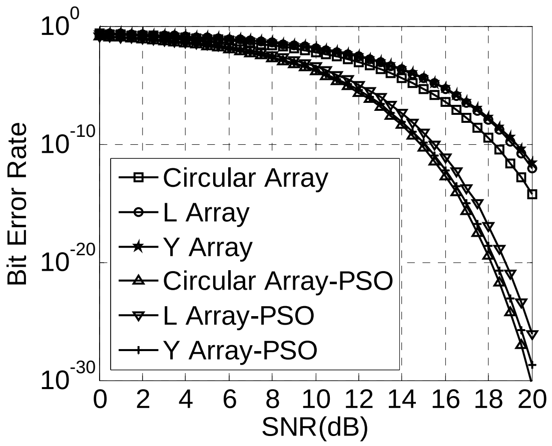

Figure 4. BER V.S. SNR for three kinds of transmitters

The BER with and without using PSO are plotted in Fig. 4. There is no obstruction between transmitter and receiver, so BER in this case are low. Fig. 4 shows the BER V.S. SNR for using three different kinds of transmitters. Here SNR is defined as the ratio of the average transmitting power to the noise power. The results show that the BER curve decreases greatly when the PSO is used as transmitter. It is due to the fact that the PSO can minimize the fading and reduce the mulitpath effects. It also can focus the synthesized antenna array pattern to optimize the available processing gain to the receiver. In Fig. 4, we can observe that for BER requirement of 10^{-5} the SNR value of L shape, Y shape, and circular shape arrays with the PSO is lower than ones without the PSO algorithm, respectively. The SNR value for these three different arrays with the PSO is larger about 4dB than that without the PSO algorithm. It is also found that the circular array has the lowest BER and the Y shape array is the second lowest.

V. CONCLUSION

Three different antenna arrays for reducing the BER in indoor wireless communication channel by the PSO algorithm are presented. The PSO algorithm minimizes the cost function (BER) where we can control the main beam direction, beam width and sidelobe level of the radiation pattern from the radiation patterns without PSO algorithm case, the transmitting signal can't reach the receiver directly. By using the PSO algorithm to improve antenna patterns, three different arrays in the indoor environment are investigated. We can observe that BER of three different antenna arrays with the PSO is lower than ones without the PSO algorithm. Numerical results show that SNR value for with the PSO is larger about 3-4 dB than that without the PSO algorithm. The BER of the circular shape array is better than L array and Y array.

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