A multi-objective optimization for UWB antenna array in indoor environment

Chien-Hung Chen
Department of Computer and Communication Engineering
Taipei College of Maritime Technology
Tamsui , New Taipei City, Taiwan
f1092@mail.tcmt.edu.tw

Ching-Yun Wu
Department of Electrical Engineering
Tamkang University
Tamsui , New Taipei City , Taiwan
tw-stantine@hotmail.com

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

Shu-Han Liao
Department of Electrical Engineering
Tamkang University
Tamsui , New Taipei City, Taiwan
bb0918@hotmail.com

***Abstract*—In this paper, a uniform circular antenna array (UCAA) combining genetic algorithm (GA) to find out global maximum of multi-objective function in indoor ultra-wideband (UWB) communication system is proposed. The GA is used to synthesize the radiation pattern of the directional UCAA to minimize the bit error rate (BER) performance and maximize received energy (RE).Using the impulse response of multipath channel, the BER performance of the synthesized antenna pattern on binary antipodal-pulse amplitude modulation(B-PAM) system can be calculated. Based on the shooting and bouncing ray / image (SBR/image) techniques, topography of the antenna and the BER formula. It can be reformulated into a multi-objective optimization problem and solved by the GA. Thus, a multi-objective problem including BER and RE as the optimization function instead of the side lobe level of antenna array pattern.**

Keywords—uniform circular antenna array; ultra-wideban; multi-objective; BER;

I. INTRODUCTION

Ultra wideband (UWB) technology is an ideal candidate for a low power, low cost, high data rate, and short range wireless communication system. According to the Federal Communication Commission (FCC)'s Report and Order in 2002 for unlicensed uses of UWB devices within the 3.1–10.6-GHz frequency band. UWB signal is defined as a signal having fractional bandwidth greater than 20% of the center frequency [1]. Ultra wide bandwidth of the system causes antenna design to be a new challenge [2]-[5]. This is because the multipath fading and interferences become more apparent than in narrow band system. In order to overcome this phenomenon, smart antennas employ arrays of antenna is envisaged as one of possible solutions [6].

Antennas may be classified as either single element or array antennas. Single element antennas may be either omni-directional or directional. Directional antennas have maximum gain to user directions and less in others. Antenna arrays may be classified as phased arrays or adaptive arrays [9]. A phased array antenna system uses an array of simple omni-directional or directional element antennas and combines the signal induced on the antennas to form an array output.

Therefore, many techniques of channel calculation have been developed in recent years. Especially, using SBR/image method to obtain impulse response is extensively applied [7]. The performance of the proposed UCAA for a UWB communication system is studied through simulations in recent years [11][12]. In the multi-objective optimization using evolutionary algorithms different objectives are aggregated and combined into one objective function using a fixed weight.

In Section II, our system description is presented. Several numerical results are included in Section III. Finally, the conclusion is drawn in section IV.

II. DESCRIPTION OF SYSTEM

A. Circular antenna array

Circular arrays are basically 1D linear arrays but in a circular form. Unlike linear arrays, distortions in the array pattern of a circular array due to mutual coupling between each element are same and this makes it easier to deal with the mutual coupling effect. We consider a circular array of eight UWB printed dipole antenna, as shown in *Fig. 1*. Each element is apart along a circle of radius Γ (=5cm) which is corresponding to the half wavelength of 3 GHz. The UWB printed dipole antenna with circular arms, which has been designed in [4][5]. The array factor of this circular antenna array can be written as:

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

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 number of elements. $k = 2\pi/\lambda$ is the wavenumber, where λ is the wavelength of the sinusoidal wave. ψ_n is the excitation current phase delay of the *n*-th element and F_n is the element excitation current amplitude of the *n*-th element. In this paper, all F_n are set to 1. X_n and Y_n are the positions of the *n*-th array element.

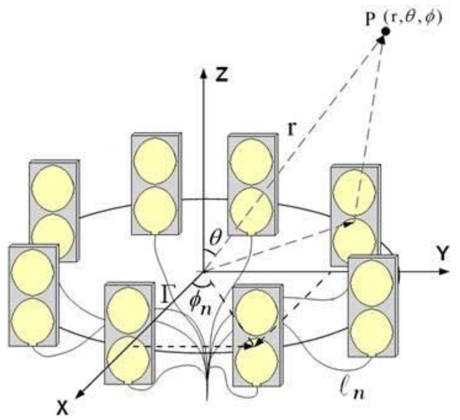

Fig. 1. Geometry of a UCAA of 8 UWB printed dipole antennas

B. Channel model of UWB

The SBR/Image method can deal with high frequency radio wave propagations in the complex indoor environments [10]. It conceptually assumes that many triangular ray tubes are shot from the transmitting antenna (TX), and each ray tube, bouncing and penetrating in the environments is traced in the indoor multi-path channel. If the receiving antenna (RX) is within a ray tube, the ray tube will have contributions to the received field at the RX, and the corresponding equivalent source (image) can be determined. By summing all contributions of these images, we can obtain the total received field at the RX. The depolarization yielded by multiple reflections on walls and floors is also taken into account in our simulations.

The frequency responses are calculated by SBR/image technique and transformed into the time domain by using the inverse Fourier transform with the Hermitian signal processing [7]. The doubled-side spectrum corresponds to a real signal in the time domain. The equation for modeling the multi-path radio channel is a linear filter with an impulse response can be written as

$$\boldsymbol{h}(\boldsymbol{t}) = \sum_{m=1}^{M_T} \alpha_m \delta(\boldsymbol{t} - \boldsymbol{\tau_m}) \tag{2}$$

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

C. Formulation of multi-objective function

The average BER for B-PAM IR UWB system can be expressed as [11][12]

$$\text{BER} = \sum_{i=1}^{2^n} P(\vec{d}) \cdot \frac{1}{2} \boldsymbol{erfc}\left[\frac{\boldsymbol{V}(\boldsymbol{i})}{\sqrt{2}\sigma} \cdot (\boldsymbol{d_n})\right] \tag{3}$$

The short dipole antenna RE is calculated by SBR/image technique and inverse Fourier transform. Those techniques are used to calculate the UWB channel impulse response for each location of the receiver.

$$\text{RE} = \int_{-\infty}^{\infty} \boldsymbol{h}(\boldsymbol{t})^2 \, \boldsymbol{dt} \tag{4}$$

Therefore, we want to minimize BER performance and maximize RE. The GA optimization is used to maximize the following fitness function.

$$\text{Fitness Function} = 1/\text{BER} + \text{RE} \tag{5}$$

D. Genetic algorithm

GA typically operates on discretized and coded representation of the parameters (excitation phase) which are to be optimized [8][11]. Using the vernaculars of the genetic algorithms, these representations are often considered to be “chromosomes” while the individual element that constitutes effective chromosomes is the “genes”. Defining a fitness function (1/BER + RE) based on desired attributes of the selecting one or more of the individuals for inclusion in an initial population, executing a GA on the initial population until defined convergence criteria are met, wherein execution of the GA has the steps of choosing the fittest individual from the population, choosing random individuals from the population and generating offspring from the fittest and chosen individuals randomly.

III. NUMERICAL RESULT

A realistic environment is investigated. It consists of a office with dimensions 10 m × 10 m × 3 m, housing one metallic cupboard and three wooden bookcases. Both of the cupboard and bookcase are 2 meter in height. The radio wave can penetrate through the wooden bookcase and is totally reflected by the metallic cupboard.

Tx and Rx1, Rx2 antennas were all mounted 1 meter above the floor. The transmitter Tx position is (2, 2, 1)m. We simulated two case with different Rx positions. case I has a line-of-sight(LOS) path to the Rx1. Tx and Rx1 are at a distance of approximately 5.7 meter. case II has non line-of-sight(NLOS) path to the Rx2, since the wooden bookcase was higher than the Tx and Rx2. The Tx - Rx2 distance on the horizontal plane is 5.8 meter in case II. The top view of the simulated environment is shown in *Fig. 2.*

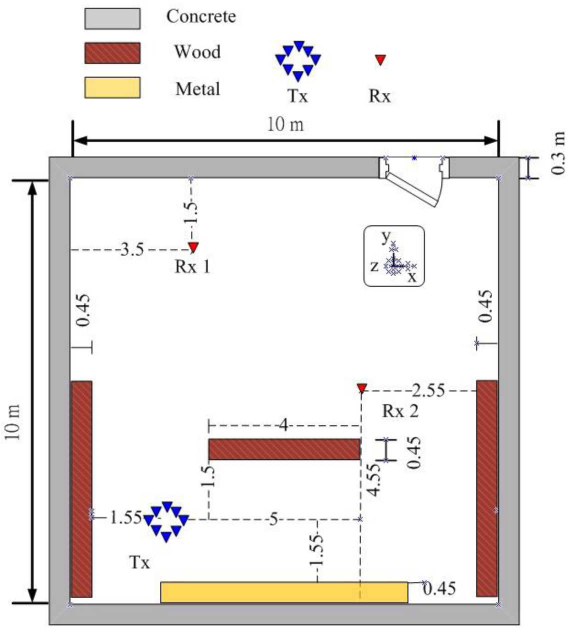

Fig. 2. top view of the simulated environment

The receiving antenna is a short dipole antenna with the height of 1m. The searching ranges of phase is 0~360 degree, respectively. The operation frequency is from 3GHz to 7GHz. LOS and NLOS cases are considered in the above. A three-dimensional SBR/Image technique combined antenna radiation pattern and GA optimization has been presented.

A. LOS case

In LOS case, the receiving antenna Rx1 is chosen at (3.5, 8.5, 1)m. The antenna array radiation pattern with and without using GA optimization are plotted in *Fig. 3.* Table I. show optimized excitation phases for each antenna element. There is no obstruction between TX and RX, so radiation pattern in this case was sharp and main beam orientated towards desired direction (85º).The BER is reduced from 10^{-2} to 10^{-5} with the GA optimization when the signal-to-noise ratio (SNR) is fixed at 50 dB is shown in *Fig. 4.*

TABLE I. OPTIMIZED EXCITATION PHASE FOR EACH ANTENNA ELEMENT (LOS CASE)

n-th element	Excitation phase(degree)
1	0
2	188.62
3	281.17
4	22.522
5	162.58
6	133.37
7	317.42
8	135.13

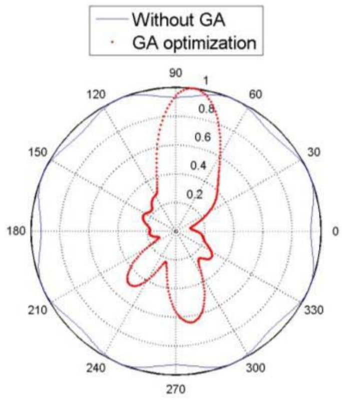

Fig. 3. Simulated patterns at 3GHz(LOS case)

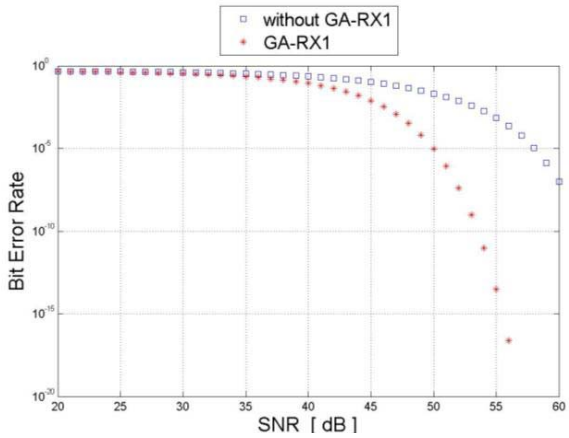

Fig. 4. BER-SNR (LOS case)

B. NLOS case

In this case, we put the Rx2 at (7, 5, 1) m. The antenna array radiation pattern with and without using GA are plotted in Fig. 5. Main beam orientated towards desired direction (33º).Table II. also show optimized excitation phases for each antenna element. Similarly, the BER is reduced from 10^{-2} to 10^{-5} with the GA when SNR is fixed at 54dB is shown in Fig. 6.

TABLE II. OPTIMIZED EXCITATION PHASE FOR EACH ANTENNA ELEMENT (NLOS CASE)

n-th element	Excitation phase(degree)
1	0
2	10.91
3	275.54
4	63.34
5	213.96
6	355.78
7	80.59
8	266.04

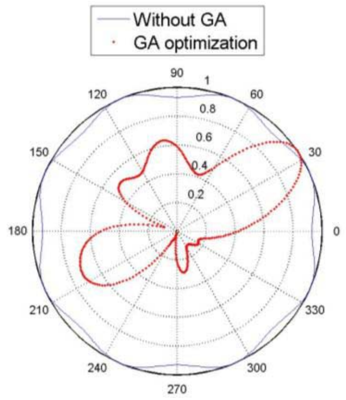

Fig. 5. Simulated patterns at 3GHz(NLOS case)

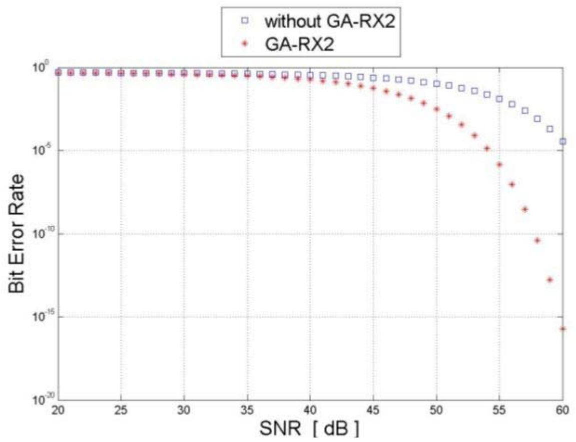

Fig. 6. BER-SNR (NLOS case)

IV. CONCLUSION

A three-dimensional SBR/Image technique combined antenna radiation pattern and GA optimization has been presented in this paper. The GA maximizes the fitness function (1/BER + RE) by adjust the excitation phase of each antenna. The BER performance of a B-PAM IR UWB communication system is investigated. Based on the BER formulation, the synthesis problem can be reformulated into an optimization problem. Table I. and Table II. show optimized excitation phases for each antenna element in LOS cases and NLOS case, respectively. Simulation results *Fig. 3.-Fig. 6.* show that the BER can be reduced and RE can be increased substantially in indoor UWB communication system.

ACKNOWLEDGMENT

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REFERENCES

[1] Federal Communications Commission, "Revision of Part 15 of the commission's rules regarding ultra-wideband transmission system, FIRST REPORT AND ORDER," FCC, ET Docket, pp. 1 – 118, Feb. 14, 2002.

[2] Dirk Manteuffel, "Radio Link Characterization using Real Antenna Integration Scenarios for UWB Consumer Electronic Applications," Ultra Wideband Systems, Technologies and Applications, 2006. The Institution of Engineering and Technology Seminar, pp.123-130, Apr. 2006.

[3] Mohamed El-Hadidy and Thomas Kaiser, "Impact of Ultra Wide-Band Antennas on Communications in a Spatial Cannel," 1st International Cognitive Radio Oriented Wireless Networks and Communications, 2006. pp.1-5, June. 2006.

[4] Sule Colak, Tan F. Wong, and A.Hamit Serbest, "UWB Dipole Array with Equally Spaced Elements of Different Lengths," 2007 IEEE International Conference on Ultra-Wideband, pp. 789 - 793, 2007.

[5] E. Gueguen, F. Thudor, P. Chambelin, "A low cost UWB printed dipole antenna with high performance," IEEE International Conference on Ultra-Wideband, pp.89-92, Sept. 2005.

[6] E. A. Homier and R. A. Scholtz, "Rapid Acquisition of Ultra-Wideband Signals in the Dense Multi-Path Channel," IEEE Conference on Ultra Wideband Systems and Technologies, pp. 105-109, 2002

[7] I. Oppermann, M. Hamalainen, and J. Iinatti, UWB Theory and Applications, John Wiley & Sons,2004.

[8] D. E. Goldberg, Genetic Algorithm in Search, Optimization and Machine Learning. Addison Wesley, 1989.

[9] Mugen Peng and Wenbo Wang, "Comparison of capacity between adaptive tracking and switched beam smart antenna techniques in TDD-CDMA systems," Microwave, Antenna, Propagation and EMC Technologies for Wireless Communications, 2005, vol. 1, pp. 135-139, Aug. 2005.

[10] S. H. Chen and S. K. Jeng, An SBR/Image Approach for Indoor Radio Propagation in a Corridor, IEICE Trans. Electron., Vol. E78-C, 1995, 1058-1062.

[11] C. H. Chen, S. H. Liao, M. H. Ho, C. C. Chiu and K. C. Chen "A Novel Indoor UWB Antenna Array Design by GA." in Proceedings of The 2009 International Conference on Future Computer and Communication (ICFCC 2009), Kuala Lumpur, Malaysia, Apr. 2009, pp. 291-295.

[12] M. H. Ho, C. C. Chiu and S. H. Liao, "Bit Error Rate Reduction for Circular UWB Antenna by DDE," International Journal of RF and Microwave Computer-Aided Engineering, Vol. 22, No 2, pp. 260-271, Mar. 2012.