Applying Direction Finding Algorithms for Obtaining Processing Gains in OFDM System with Multiple Receiving Antennas

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Abstract

In this paper, the error probability performance of an OFDM system with multiple receiving antennas in a frequency selective fading channel is presented. In the receiving system, we use the adaptive direction of arrival (DOA) algorithm, MUSIC, to track each user's location. According to the DOA information, the antenna array creates a directive beam pattern to each user. Then, the received user's signal can get an additional antenna processing gain to beat frequency selective fading impairment and other directions' interferences. By utilizing multiple antennas in the OFDM system, as shown in the simulation results, the error probability performance could be sufficient improved even the DOA estimation with several degree of errors.

I. Introduction

In recent years, there are lots of techniques to improve the system performance; Orthogonal Frequency Divided Multiplex (OFDM) system is a well-known technique for a high data rate transmission system, like wireless LAN. It provides multi-orthogonal frequencies to carry more amounts of data and avoid multi-access interferences (MAI) by adding cyclic prefix (CP) [1]. From the other hand, Smart Antenna (SA) is another popular subjects [2]. It provides the multi-access methods in a spatial domain. Using direction finding algorithms, we can estimate the direction-of-arrival (DOA) information of the different mobile users with antenna array receiving system. According to the direction information, the array antenna can create the antenna gain pattern to each user, and add the gain to the received signals. The system will get better SNR performance in a radio propagation channel. In this paper, we construct a basic OFDM system with multiple receiving antennas in a frequency selective fading channel. The proposed system uses the adaptive DOA algorithm, MUSIC [3], in wideband channel environments to track each user's major DOA. So, the receiving system will get an additional antenna gain to each user. Besides, we compare and analyze the system enhancement by using direction finding technique in OFDM system. Finally, simulation results with some conclusions are presented.

II. System model

The block diagram of the proposed OFDM system with multiple receiving antennas is shown in Fig. 1. At the beginning, source data will modulate to the MPSK signal. The sequence data convert to parallel form and transfer by IFFT. The cyclic prefix adds here. Then, these transmitted sequences do convolution calculation with a frequency selective fading channel. In this paper, the frequency selective fading channel model references from HiperLan/2 specification channel model [4, 5]. And each multi-path will involve its angle information. In the other word, the frequency selective fading channel becomes a vector wideband channel model [6, 7]. At the receiving end, the OFDM system adds an antenna array structure; here we use 4 antenna elements. According to each antenna array received signal, we can estimate the major DOA of the user by MUSIC algorithm. Using this direction information, the oriented antenna beam pattern will provide its own antenna gain, the gain will progress the receiving signal power then obtain better bit error rate (BER) performance.

0-7803-7846-6/03/$17.00 ©2003 IEEE

The transmitted signal of the proposed OFDM smart antenna system can be expressed as

$$X(t) = F^H(n)S(n)$$

where,

$S(n)$: Data symbols in Freq. Domain;

t : Time index; n : OFDM subcarrier index;

$$X(t) = \begin{bmatrix} x_{0,m} \\ x_{1,m} \\ . \\ . \\ x_{N-1,m} \end{bmatrix}_{N*M}, S(n) = \begin{bmatrix} s_{0,m} \\ s_{1,m} \\ . \\ . \\ s_{N-1,m} \end{bmatrix}_{N*M}, F(n) = \begin{bmatrix} 1 & 1 & \cdots & \cdots & 1 \\ 1 & e^{-j2\pi(1)(1)/N} & \cdots & \cdots & e^{-j2\pi(1)(N-1)/N} \\ . & . & \cdots & \cdots & . \\ . & . & \cdots & \cdots & . \\ 1 & e^{-j2\pi(N-1)(1)/N} & \cdots & \cdots & e^{-j2\pi(N-1)(N-1)/N} \end{bmatrix}_{N*N}$$

N : Number of subcarriers; M : Number of blocks.

At the receiving part, the received signal

$$Y(t) = A(\theta)H(t,\tau) \otimes X(t) + N(t);$$

where

$H(t,\tau)$: Frequency selective fading channel response, including 4 multipaths;

$N(t)$: Additive white Gaussian noises;

$$Y(t) = \begin{bmatrix} y_{0,m} \\ y_{1,m} \\ . \\ . \\ y_{N-1,m} \end{bmatrix}_{N*M}, A(\theta) = [a(\theta_1) \quad a(\theta_2) \quad a(\theta_3) \quad a(\theta_4)], H(t,\tau) = \begin{bmatrix} h_{1,1} & . & . & h_{1,4} \\ . & . & . & . \\ . & . & . & . \\ h_{t,1} & . & . & h_{t,4} \end{bmatrix}, N(t) = \begin{bmatrix} n_{0,m} \\ n_{1,m} \\ . \\ . \\ n_{N-1,m} \end{bmatrix}_{N*M}$$

$$a(\theta) = \begin{bmatrix} 1 \\ e^{-j\beta d 1\cos\theta} \\ . \\ . \\ e^{-j\beta d(K-1)\cos\theta} \end{bmatrix}_{K*1}$$: Antenna array response,

K : Number of antennas; $\beta = 2\pi/\lambda$; $d = \lambda/2$: Distance between antennas;

The above equations represent the signal models at both transmission and receiving ends. We utilize the MUSIC algorithm to estimate the DOA of different users.

The MUltiple SIgnal Classification (MUSIC) algorithm can be summary as:

Step1: Compose the input covariance matrix

$$R_{yy} = \frac{1}{K}\sum_{t=1}^{K} Y(t)Y(t)^H$$

Step2: Perform eigen decomposition on R_{yy}

$$R_{yy}V = V\Lambda$$

where

$V = [q_1 q_2 \ldots q_K]$ is the corresponding eigenvector of R_{yy} ;

$\Lambda = diag\{\lambda_0, \lambda_1, \ldots \lambda_{K-1}\}$, λ is the eigenvalue of R_{yy}

Step3: Estimate the number of the signals D , form the multiplicity P , of the smallest eigenvalue $\lambda_{\min}$ as

$$D = K - P$$

Step4: Computer the MUSIC spectrum

$$P_{music}(\theta) = \frac{a^H(\theta)a(\theta)}{a^H(\theta)V_n V_n^H a(\theta)}$$

As show in Fig2, there are 4 different multipaths from directions: $[60°,59°,56°,58°]$. Our proposed algorithm only estimates the major DOA. In Table1, Different SNR environment get different estimated DOA degree. Though the estimated degree isn't match the line of sign (LOS) path degree well, the estimated angles at different SNR values are very close. The MUSIC algorithm is usually used in a narrowband smart antenna system. The MUSIC algorithm has no ability to estimate all DOA paths. However major DOA can be resolved in such a wideband channel environment. Although the degree isn't exactly correct, the main lobe of the beam pattern still could provide some antenna gain for each user. In Fig3, we compare the BER performance between OFDM system and OFDM system with multiple antennas. Although MUSIC algorithm cannot estimate the accuracy DOAs of all multipaths, the OFDM system with antenna array still can provide the antenna processing gain. As long as the angle spread of each user limited in ten-degree range that is almost true in indoor wireless LAN applications, the main bean could be formed toward the major DOA of that particular mobile user. Thus, the system can still have antenna gain and be able to enhance the BER performance, no matter the DOA estimation is exactly or not.

III. Conclusions

By utilizing multiple antennas in the OFDM system, as shown in the simulation results, the error probability performance could be sufficient improved even the DOA estimation with several degree of errors. Though the MUSIC algorithm is usually used in narrowband system, we proposed a feasible application of utilizing direction finding algorithm for frequency selective fading channels. In the next step, we expect to utilize the DOA algorithms more efficiently. On the other hand, we don't use the whole OFDM advantages in this system. In an OFDM system, we can assume a wideband channel signal could be separated into several narrowband signals. Then, we could resolve DOA information more exactly in the frequency selective multipath wideband fading channel. Furthermore, we can modify the direction finding algorithm in both time and frequency domains to fit the real mobile user scenarios, and get better BER performance on the OFDM smart antenna system.

IV. Reference

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SNR	1	2	3	4	5	6	7	8	9	10
Degree	59°	61°	58°	59°	62°	59°	61°	60°	60°	59°

Table 1. The estimated DOA vs. SNR values

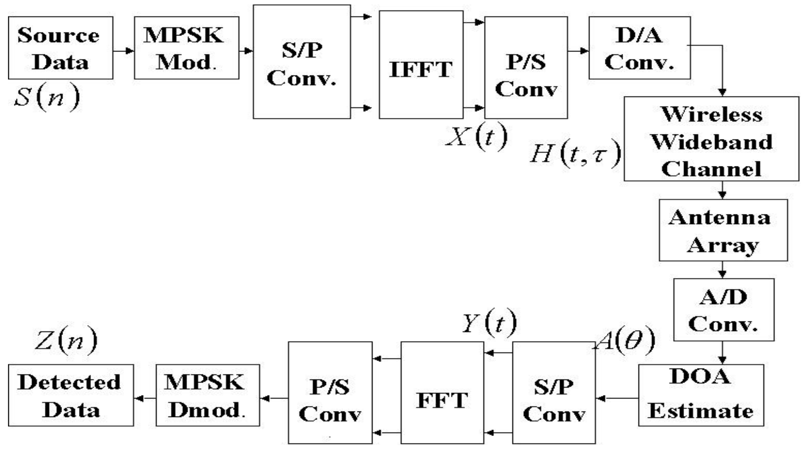

Fig 1.A block diagram of an OFDM system with multiple receiving antennas

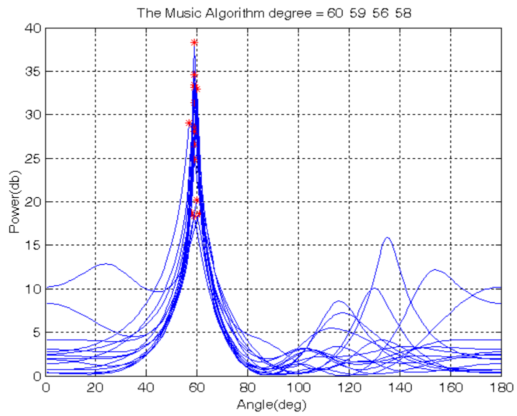

Fig 2.Beam pattern of the MUSIC algorithm for varies degrees of paths
Different blue line means different SNR; the star dot means the estimated DOA.

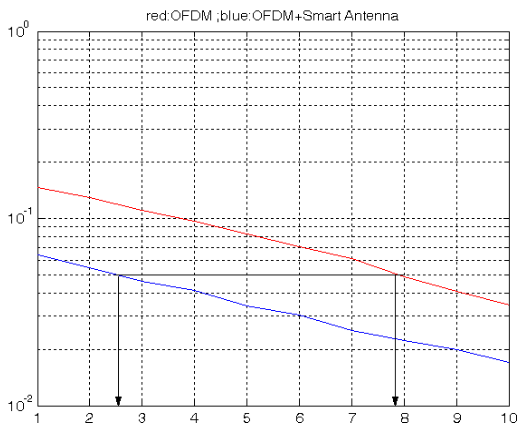

Fig 3.The BER comparison of OFDM system and OFDM with antenna array
Red Line: OFDM; Blue Line: OFDM+ Smart Antennas