AN ADAPTIVE BEAMFORMING TECHNIQUE FOR OFDM-BASED SMART ANTENNA SYSTEM IN MULTIPATH FADING CHANNEL

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ABSTRACT

Multiple antenna technology, such as multiple-input multiple-output(MIMO) or beamforming has been known as the most promising technology for broadband wireless communication. In OFDM environment, however beamforming system cannot fully exploit beamforming gain because each path is divided in multipath fading channel. In this paper, we propose a beamforming technique for the OFDMA system and analyze the performance of the proposed beamforming technique for WiBro/WiMAX, which is based on an OFDMA wireless broadband multimedia environment. The proposed beamforming technique can further improve the required SNR(Signal to Noise Ratio) by approximately 3dB and 1.5dB compared to conventional beamforming technique in vehicular and pedestrian channel environment, respectively.

1. INTRODUCTION

The next generation wireless systems are required to have high voice quality as compared to current mobile service. And customers are expecting high quality, reliability and easy access to high-speed communications. In addition, the next generation systems are supposed to have better quality and coverage, be more power and bandwidth efficient. Multiple antennas system generally provides performance improvement without bandwidth or transmit power increase. Smart antenna system is an innovative technology for broadband wireless communication that increases communication capacity and quality. In the past few years, there have been many studies of OFDM-based smart antenna systems.

Orthogonal Frequency Division Multiplexing(OFDM) is a transmission technique that subdivides the total bandwidth into multiple narrowband subcarriers. In an OFDM system, the input data stream is divided into several parallel sub-streams of reduced data rate and each sub-stream is modulated and transmitted on a separate orthogonal sub-carrier. Thus the increased symbol duration improves the robustness of OFDM to delay spread. OFDM system adopts guard interval to fight ISI over the broadband channel and has been less affected by frequency selective fading owing to multiple narrowband subcarriers. Furthermore, by overlapping orthogonal subcarriers, OFDM system provides an efficient frequency spectrum usage compared to conventional FDM system.

In this paper, the performance of smart antenna beamforming techniques is compared and analyzed for OFDMA-based wireless communication standard, WiBro/WiMAX Uplink environment. Based on IEEE 802.16-2004 [2] and 802.16e-2005 [3], WiBro (Wireless Broadband) is the next generation wireless communication standard for portable internet service that is using 10MHz bandwidth at 2.3GHz center frequency.

The organization of this paper is as follows: In Section Ⅱ, we presents the smart antenna system model and beamforming techniques. In section Ⅲ, we examine the structure of WiBro/WiMAX uplink system. Simulation results are shown in section Ⅳ. Section Ⅴ concludes this paper.

2. ADAPTIVE BEAMFORMING TECHNIQUE

2.1 System model

We consider the smart antenna system that is equipped with M antenna element. Array antenna is spaced out a half wavelength at the carrier frequency of the signals. For simplicity, each antenna element is assumed to be omni-directional. The baseband signal of mobile terminal, which is transmitted to the base station in the uplink channel, is denoted by $s(t)$. Then, the received signal can be written as

$$\underline{y}(t) = \sum_{k=1}^{K} s(t-\tau_k) h_k(t) \underline{a_k}(\theta_k) + \underline{n}(t) \qquad (1)$$

Where, τ_k and $h_k(t)$ are the propagation path delay and

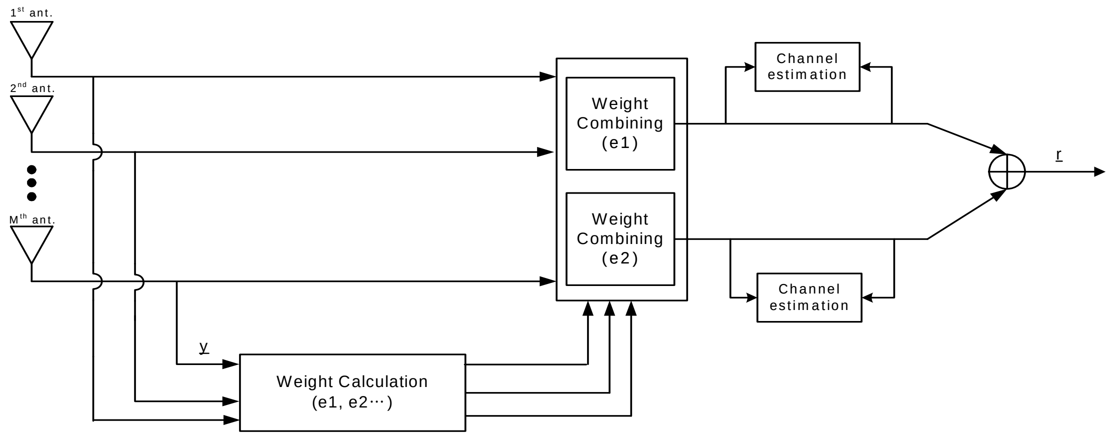

Fig. 1. Structure of the Proposed Smart Antenna system using two Eigenvectors

the k-th tap discrete-time channel response, respectively. k is the number of multipaths. $\underline{\bullet}$ term indicates a vector. θ_k is an incident angle of $s(t)$, and $\underline{a_k}(\theta_k)$ is steering vector of k-th channel. and $\underline{n}(t) \sim N_c(0, \sigma^2 \underline{\underline{\mathbf{I}}})$.

The frequency response of the channel in smart antenna system can be written as follows:

$$\underline{\tilde{H}}(t) = \sum_{k=1}^{K} h_k(t)\underline{a_k}(\theta_k) \tag{2}$$

For a certainty, the optimal beamforming vector is the eigenvector that corresponds to the maximum eigenvalue of $\underline{\tilde{H}}^H \underline{\tilde{H}}$.

2.2 Beamforming techniques

In this section, we propose the beamforming technique of using many eigenvectors. Define the covariance matrix of the channel as below[1].

$$\underline{\underline{R}}_{\tilde{H}} = E\left[\underline{\tilde{H}}^H(t)\underline{\tilde{H}}(t)\right] \tag{3}$$

Where, $E[\bullet]$ term indicates expectation. $\underline{\underline{\bullet}}$ term indicates a matrix. In (3), we assume that the covariance matrix does not depend on time t. From the eigen-decomposition of $\underline{\underline{R}}_{\tilde{H}}$, $\underline{\underline{R}}_{\tilde{H}}$ has real non-negative eigenvalues and orthonormal eigenvectors.

$$\underline{\underline{R}}_{\tilde{H}} = E_k \Lambda_k E_k^H \tag{4}$$

Where, $E_k = [\underline{e_1}\,\underline{e_2} \ldots \underline{e_k}]$ and $\Lambda_k = diag(\lambda_1, \lambda_2, \ldots, \lambda_k)$. Here, $\lambda_1 \ge \lambda_2 \ge \cdots \ge \lambda_k$ are the eigenvalues of $\underline{\underline{R}}_{\tilde{H}}$, and $\underline{e_k}$ is the eigenvector that corresponds to λ_k.

Thus, the optimal eigenvector is $\underline{e_1}$ that corresponds to the maximum eigenvalue of $\underline{\underline{R}}_{\tilde{H}}$. In general, we have beamforming gain when the optimal eigenvector is used as the weight vector. Here, maximum SNR gain of the N array antenna is $10\log(N)$. Beamforming gain increases as the number of antennas is increased.

In OFDM environment, as the number of paths is increased, smart antenna system cannot fully exploit beamforming gain. Because the optimal weight vector of the each path is different, one weight vector is difficult to in-phase all paths.

In this paper, we investigate the beamforming technique of combining many eigenvector. And we assume that the MRC(Maximum Ratio Combining) is used at the receiver. This beamforming technique can achieve beamforming gain and diversity gain.

For simplicity, we assume the beamforming technique of combining two eigenvector as shown in figure 1. Here, received signal from (1) and (2) is briefly written as

$$\underline{y} = s \cdot \underline{\tilde{H}} + \underline{n} \tag{5}$$

Output signal after MRC of the array signal using the two eigenvector can be computed by

$$\begin{aligned} r &= \underline{e_1}^H \cdot \hat{h}_1 \cdot \underline{y} + \underline{e_2}^H \cdot \hat{h}_2 \cdot \underline{y} \\ &= (\underline{e_1}^H \cdot \hat{h}_1 + \underline{e_2}^H \cdot \hat{h}_2) \cdot \underline{y} \\ &= (\underline{e_1}^H \cdot \hat{h}_1 + \underline{e_2}^H \cdot \hat{h}_2) \cdot (s \cdot \underline{\tilde{H}} + \underline{n}) \end{aligned} \tag{6}$$

Where, $\hat{h}_1, \hat{h}_2$ is the estimated channel after received signal is combined with weight vectors. And we know that $\underline{\tilde{H}}$ is expressed by $(h_1 \cdot \underline{e_1} + h_2 \cdot \underline{e_2} + \cdots)$ from (2).

Hence, detected signal r is expressed by

$$r = \left(|h_1|^2 + |h_2|^2\right) \cdot s \tag{7}$$

From (7), we gain some insight. We can have a diversity gain. In addition, we know that the performance can be improved by the beamforming gain.

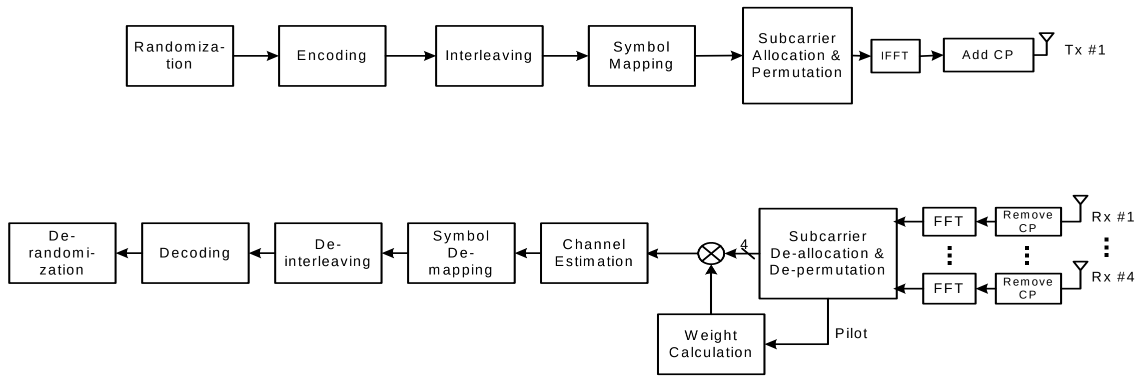

Fig. 2. WiBro/WiMAX Smart antenna system Uplink Block Diagram

3. STRUCTURE OF WIBRO/WIMAX SYSTEM

In this section, we consider a structure of WiBro/WiMAX system that is an OFDMA-based multiple access service.
The transmitter of WiBro/WiMAX system performs a randomization of information, channel encoding, interleaving, repetition after slot concatenation that divide slot into FEC block. And then a modulation to generate data subcarriers and arrangement of the data subcarriers and pilot subcarriers corresponding to pre-defined pattern. After IFFT operation, time domain OFDM signals are generated. Then, CP (Cyclic Prefix) is added before up-converting for RF transmission. At the receiver, inverse order of operation is performed. In case of the smart antenna system, weight vector is combined after subcarrier De-permutation. And then channel estimation process is performed. Figure 2 shows the block diagram of transmitter and receiver for WiBro/WiMAX system.

4. SIMULATION RESULTS

This section presents a performance analysis of the proposed beamforming system. Performance analysis of the smart antenna system is shown in terms of BER(Bit Error Rate) in WiBro/WiMAX Uplink environment. Simulation parameters are listed in Table 1.

Figure 3 shows BER performance of smart antenna system as the number of antenna elements increases.

As shown in figure 3, it is observed that the BER performance do not becomes much better as the number of antenna elements increases.

Figures 4 and 5 illustrate the BER performance of single antenna system, beamforming technique of using one eigenvector(e1) and beamforming technique of using two eigenvectors(e1, e2) in multi-path fading channel. Figures 4 and 5 show the performance of the beamforming system in vehicular and pedestrian channel environment, respectively.

Table 1. Simulation parameters

Parameters	**Value**
Subcarrier Permutation Mode	PUSC
Carrier Frequency	2.3 GHz
Channel Bandwidth	8.75 MHz
FFT Size	1024 point
Number of Data Subcarriers	720
Number of Pilot Subcarriers	120
TDD Frame Length	5ms
CP(Cyclic Prefix) Ratio	1/8
Doppler Frequency	127 Hz
Data Modulation	QPSK
Channel Coding (Coding Rate)	Convolutional Coding (1/2)
Number of Tx Antennas	1
Number of Rx Antennas	1 or 4
Number of Used Slots	20

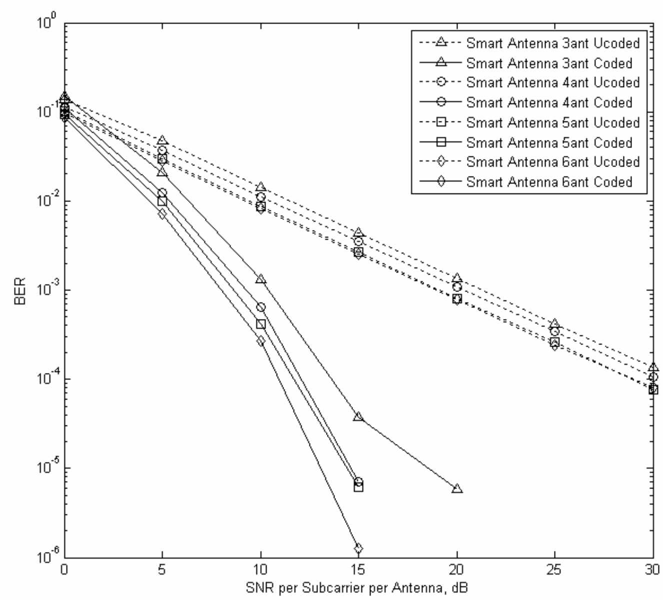

Fig. 3. Average BER performance according to antenna number for smart antenna system

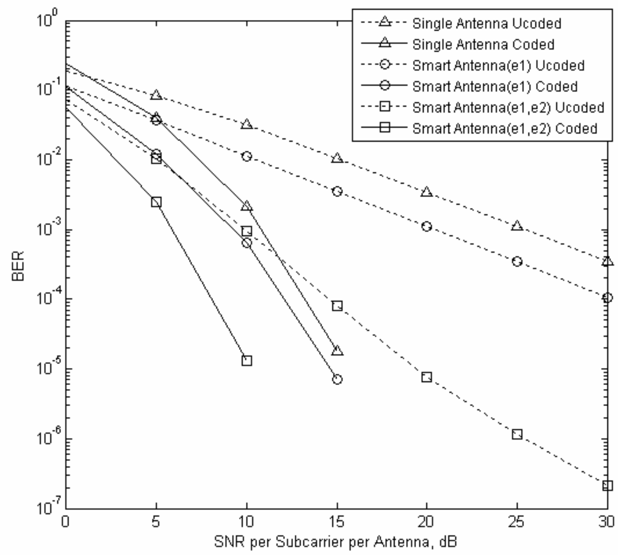

Fig. 4. Average BER performance for beamforming techniques (vehicular environment)

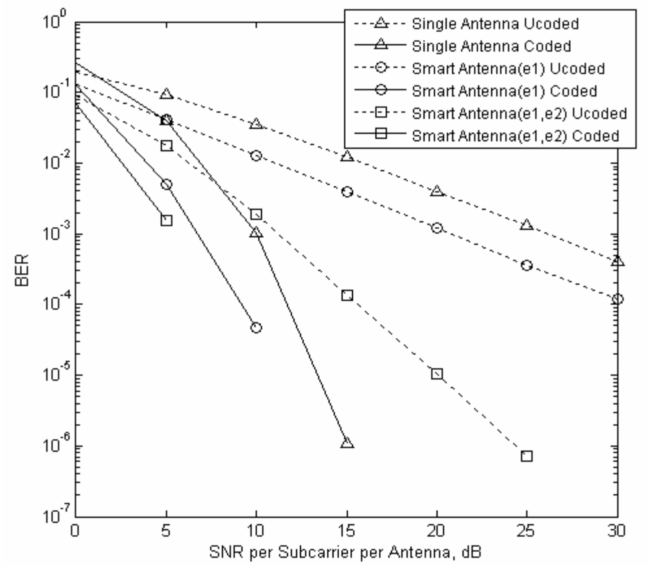

Fig. 5. Average BER performance for beamforming techniques (pedestrian environment)

As shown in figures 4 and 5, it is observed that for the BER 10^{-3}, beamforming technique of using one eigenvector(e1) obtains around 2.5dB gain in SNR compared to single antenna system in case of coded ber. In general, the SNR gain can be obtained from array beamforming gain of which the theoretical value can be at most 6dB($10\log(4)$). In OFDM environment, one weight vector cannot in-phase all paths because multipath cannot be divided. Thus, the decrease of SNR gain in OFDM multipath fading channel environment is occurred.

But beamforming technique of using two eigenvectors(e1, e2) presents much better performance than beamforming technique of one eigenvector(e1). For the BER 10^{-3}, the beamforming technique of using two eigenvectors(e1, e2) obtains about 3dB and 1.5dB gain in SNR compared to beamforming technique of using one eigenvector(e1) in vehicular and pedestrian channel environment, respectively.

5. CONCLUSION

This paper presents a beamforming OFDM signal processing and a performance analysis that supports WiBro/WiMAX system. As shown in simulation results, the smart antenna system provides the better performance than single antenna system. But in OFDM environment, the smart antenna system cannot fully have a beamforming gain in multipath fading channels. Thus, the beamforming technique utilizing many eigenvectors can obtain not only beamforming gain but also diversity gain. By exploiting the diversity gain, the beamforming technique utilizing many eigenvectors can improve a performance in multipath fading channel environment.

6. ACKNOWLEDGEMENT

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