IMPROVED BEAMFORMING SCHEME WITH PHASE INFORMATION OF CHANNELS

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Abstract- Beamforming is a signal processing technique for directional transmission or reception of signals. On the other hand, diversity technique is used to mitigate degradation due to unstable fading channels. To alleviate computational burden for mobile stations, transmit antenna diversity is applied in base stations. Without additional time or frequency resource, this paper proposes an improved beamforming scheme by using transmit diversity in the base station. In slow fading channel conditions, we design a precoder which utilizes the phase of uplink channel state information (CSI). With the same number of total transmit antennas, the proposed method obtains diversity gain and also signal-to-noise ratio (SNR) gain compared to traditional beamforming.

Keywords- Antenna Array, Beamforming, Transmit Diversity, Wireless Communication

I. INTRODUCTION

Shifting the phases of an antenna array elements, a unique radiation is achieved in beamforming systems. Then we can combine the phased signals at the receiver which come from particular angles that experience constructive interferences.

Diversity technique is used to mitigate degradation in the error performance due to unstable fading channels. There are various ways of realizing diversity gain. Especially, antenna diversity does not require much additional time or frequency resource. We can obtain antenna diversity gain at the transmitter or receiver. Receive diversity utilizes multiple antennas at the receiver and performs combining or selection to improve the performance. However, for a mobile station, there are limitations with the number of antennas and the computational burden which may incur high power consumption. Therefore, diversity at the transmitter is also needed to be considered which can alleviate computational burden at the receiver.

There have been many research which combined beamforming and space-time block code (STBC). A beamforming scheme combined with quasi-orthogonal STBC using four beamformers was proposed. Then, a combined beamforming and STBC scheme for multiple-input multiple-output (MIMO) environment was presented. Recently, a spatial multiplexing MIMO scheme with beamforming and STBC was proposed.

With the CSI, we propose an improved beamforming scheme by using transmit diversity with simple calculation in this paper. In slow fading channel conditions, we design a precoder by utilizing the phase of uplink CSI so that transmit diversity gain is achieved. With the same number of total transmit antennas, the proposed method provides better performance than that of the traditional beamforming scheme.

II. TRADITIONAL BEAMFORMING

A. System Model

Fig. 1 illustratesa baseband block diagram of traditional beamforming scheme.At a given time, an information bit is sent to M-ary phase shift keying (MPSK) modulator. The output signal is sent to uniform linear array (ULA) withN antenna elements. Channels from each transmit antenna array element to the receiver are assumed to be independent flat Rayleigh fading. The receiver with single antenna recovers the signal through maximum likelihood (ML) detection.

B. Transmitter

The information bit is first modulated using MPSK. After that, the output signal s is passed into the beamformer with beamforming weight vector$a^*(\theta)$ which utilizes the uplink direction of arrival (DOA) of the antenna array. The beamforming weight vector can be expressed as

$$a^*(\theta) = \begin{bmatrix} 1 & e^{-j\frac{2\pi}{\lambda}d\sin\theta} & \cdots & e^{-j\frac{2\pi}{\lambda}(N-1)d\sin\theta} \end{bmatrix}^H, \quad (1)$$

where λ is the wavelength of the carrier frequency, d is the distance between each antenna element, θ is the DOA of the antenna array, $[\cdot]^*$denotes complex conjugate, and $[\cdot]^H$ denotes conjugate transpose.

The baseband signal after passing the beamformer is written as

$$s_{BF} = a^* s, \quad (2)$$

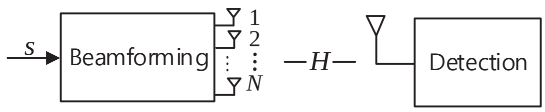

Figure 1: The block diagram of traditional beamforming scheme

where $E[|s|^2]=1/N$ and each element of the vector s_{BF} is transmitted from each antenna element. Here, E denotes expectation operation.

C. Channel

We assume that each channel between the transmit antenna array elements and the receiver antenna is independent flat Rayleigh fading. The channel matrix is expressed as

$$H=[h_1\ h_2\ \cdots\ h_N], \tag{3}$$

where $h_i\,(i=1,\cdots,N)$ arethe fading coefficients from the i-th element of the antenna array and independent identical distributed (i.i.d.) Gaussian random variable with zero mean and unit variance.

The fading coefficients are constant during one symbol period.

D. Receiver

The resulting received baseband signal can be derived as

$$r = H s_{BF} + n = h_{EQ} s + n, \tag{4}$$

whereh_{EQ}=Ha^* and$n$ represents a complex Gaussian noise with zero mean and variance σ^2.

By canceling the effect of the channel, the estimated signal at the receiver is derived as

$$\hat{r} = \frac{h^*_{EQ}}{|h_{EQ}|^2} r = s + \frac{h^*_{EQ}}{|h_{EQ}|^2} n. \tag{5}$$

Then, the average instantaneous SNR of the received signal r is

$$SNR = \frac{E\left[|s|^2\right]}{\frac{1}{|h_{EQ}|^2} E\left[|n|^2\right]} = \frac{|h_{EQ}|^2}{N\sigma^2}. \tag{6}$$

Since h_{EQ}=$Ha^*$is a linear combination of the channel elements of H, $h_{EQ}$is a complex Gaussian random variable with zero mean and variance

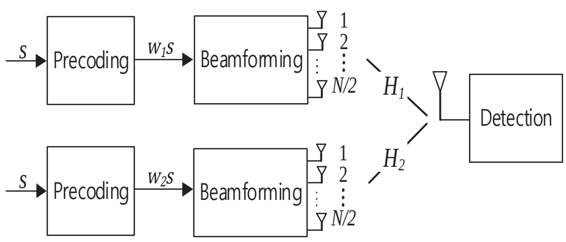

Figure 2: The block diagram of improved beamforming scheme

$$\varepsilon_H[h^*_{EQ} h_{EQ}] = \varepsilon_H[H^* aHa^*] \\ = \sum_{i=1}^{N} \varepsilon_H[|h_i|^2] = N. \tag{7}$$

Equivalently, the signal s is degraded by a Rayleigh fading with N times channel gain of original channel path h_i.

Thus, the average SNR is derived as

$$\varepsilon_H[SNR] = \frac{\varepsilon_H\left[|h_{EQ}|^2\right]}{N\sigma^2} = \frac{1}{\sigma^2}. \tag{8}$$

III. IMPROVED BEAMFORMING SCHEME

A. System Model

In order to achieve a better bit error rate (BER) performance, we propose an improved beamforming scheme by using transmit diversity. Fig. 2illustratesa baseband block diagram of the improved beamforming scheme.First of all, an information bit is sent to an MPSK modulator. Before passing the beamformer, the output signal is sent to a precoder that multiplies a complex number that utilizes the uplink CSI under slow fading channel conditions. Then the output signals are sent to the beamformers. There are two ULAs with N/2 elements, respectively. Channels from each transmit antenna array element to the receiver are independent flat Rayleigh fading. The single antenna receiver recovers the signal through ML detection.

B. Transmitter

The information bit is first modulated using MPSK. The output signal s is sent to the precoder. If slow fading channel conditions, we can utilize the uplink CSI for determining the precoding weights. The precoder multiplies the modulated signal by complex numbers expressed as w_1, w_2 corresponding to the inverse of the phase of the fading coefficients, which will be determined precisely later.

Precoded signals are then passed into the beamformer with beamforming weight vectors $a_i^*(\theta_i)\ (i = 1, 2)$which utilizes the uplink DOA of each antenna array. The beamforming weight vectors can be expressed as

$$a_1^*(\theta_1) = \left[1\ e^{-j\frac{2\pi}{\lambda} d \sin\theta_1}\ \cdots\ e^{-j\frac{2\pi}{\lambda}(N/2-1) d \sin\theta_1}\right]^H \tag{9}$$

$$a_2^*(\theta_2) = \left[1\ e^{-j\frac{2\pi}{\lambda} d \sin\theta_2}\ \cdots\ e^{-j\frac{2\pi}{\lambda}(N/2-1) d \sin\theta_2}\right]^H, \tag{10}$$

where θ_1, θ_2 are the DOAs of the each antenna array. The number of elements at each antenna array is N/2.

The baseband transmit signals are derived as

$$s_{BF,1} = a_1^* w_1 s \tag{11}$$

$$s_{BF,2} = a_2^* w_2 s, \tag{12}$$

where $E[|s|^2] = 1/N$ is also assumed.

C. Channel

As before, we assume that each channel between the transmit antenna array elements and the receiver antenna is independent flat Rayleigh fading. The channel between transmitter and receiver can be expressed as

$$H_1 = \left[h_{1,1}\ h_{1,2}\ \cdots\ h_{1,N/2}\right] \tag{13}$$

$$H_2 = \left[h_{2,1}\ h_{2,2}\ \cdots\ h_{2,N/2}\right], \tag{14}$$

where $h_{j,i}\,(i=1,\cdots,N/2,\ j=1,2)$ arethe fading coefficients from the i-th element of the j-th antenna array and follows complex Gaussian random variable with zero mean and unit variance. The fading coefficients are constant during one symbol period.

D. Receiver

The received baseband signal is

$$\begin{aligned} r &= H_1 s_{BF,1} + H_2 s_{BF,2} + n \\ &= (h_{EQ,1} w_1 + h_{EQ,2} w_2) s + n, \end{aligned} \tag{15}$$

where$h_{EQ,i}$(i =1,2) is the equivalent channel expressed as

$$h_{EQ,1} = H_1 a_1^* = \left|h_{EQ,1}\right| e^{j\phi_1} \tag{16}$$

$$h_{EQ,2} = H_2 a_2^* = \left|h_{EQ,2}\right| e^{j\phi_2}. \tag{17}$$

To improve the received SNR, we adopt the inverse of the phases of these equivalent channels to make the precoding weights, i.e.,

$$w_1 = e^{-j\phi_1} \tag{18}$$

$$w_2 = e^{-j\phi_2}. \tag{19}$$

Multiplying the equivalent channels by these weights, we can remove the phase and only take the amplitude of the equivalent channel to achieve transmit diversity. In detail,

$$\begin{aligned} r &= (h_{EQ,1} w_1 + h_{EQ,2} w_2) s + n \\ &= \left(\left|h_{EQ,1}\right| + \left|h_{EQ,2}\right|\right) s + n, \end{aligned} \tag{20}$$

where$h_{EQ,1}$and $h_{EQ,2}$are two independent complex Gaussian random variables with zero mean and variance

$$\begin{aligned} \varepsilon_H[h_{EQ,i}^* h_{EQ,i}] &= \varepsilon_H[H_i^* a_i H_i a_i^*] \\ &= \sum_{i=1}^{N/2} \varepsilon_H[|h_i|^2] = N/2. \end{aligned} \tag{21}$$

Equivalently, the signal s passed through two independent Rayleigh fading channels with N/2 times channel gain of the original channel path h_i, where a path diversity is obtained.Moreover, an improved average SNR is derived as

$$\begin{aligned} &\varepsilon_H[SNR] \\ &= \frac{\varepsilon_H\left[\left(\left|h_{EQ,1}\right| + \left|h_{EQ,2}\right|\right)^2\right]}{N\sigma^2} \\ &= \frac{\varepsilon_H\left[\left|h_{EQ,1}\right|^2\right] + \varepsilon_H\left[\left|h_{EQ,2}\right|^2\right] + 2\varepsilon_H\left[\left|h_{EQ,1}\right|\right]\varepsilon_H\left[\left|h_{EQ,2}\right|\right]}{N\sigma^2} \\ &= \frac{\frac{N}{2} + \frac{N}{2} + 2\frac{N\pi}{8}}{N\sigma^2} = \frac{1 + \frac{\pi}{4}}{\sigma^2}. \end{aligned} \tag{22}$$

Without a doubt, the average SNR of the proposed beamforming scheme is larger than that of the traditional scheme.

IV. SIMULATION

We consider one ULA for the traditional beamforming scheme and two ULAs with 10 wavelengths array spacing for the proposed method, which means no correlation between antenna arrays. Each antenna element is spaced at half the wavelength. Without channel coding, a binary-PSK (BPSK) modulated symbol is used at the transmitter and ML detection is adopted at the receiver. It is assumed that the total transmit power from N antennas equals one for both systems. It is also assumed that the transmitter

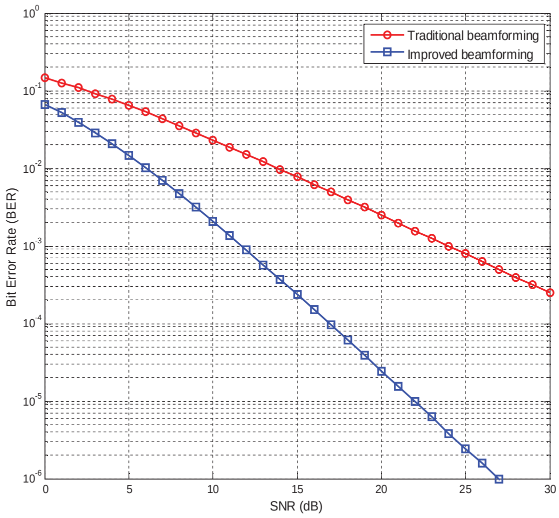

Figure 3: The performance comparison of traditional beamforming and improved beamforming scheme in Rayleigh fading channel

knows the perfect channel phases and DOA from uplink transmission.

Fig. 3 shows the BER performance comparison of the traditional beamforming scheme with the improved beamforming scheme in a Rayleigh fading channel. From the simulation, we can see that the proposed method shows the better performance than that of the traditional one. Curve slope of the proposed method is twice of the traditional beamforming scheme, i.e., achieves diversity 2. Also, a 12dB SNR gain in BER of 10^{-3} is achieved as compared in (8) and (22).

CONCLUSION

In this paper, we proposed an improved beamforming scheme using the phase information of uplink CSI to achieve diversity gain. We showed that the proposed method achieves diversity 2 and provides SNR improvement compared to the traditional beamforming scheme with the same number of total transmit antennas. The proposed method which helps the mobile station achieve diversity gain with single antenna will be a simple and valuable scheme in wireless communication systems.

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