

ADAPTIVE TRANSMISSION POWER CONTROL FOR MIMO DIVERSITY EMPLOYING POLARIZATION DIVERSITY IN OFDM RADIO ACCESS

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ABSTRACT

This paper proposes an adaptive transmission power control scheme between cross-polarized transmission antennas for multiple-input multiple-output (MIMO) diversity using polarization diversity in orthogonal frequency division multiplexing (OFDM), in order to mitigate the degradation due to the effect of cross polarization discrimination (XPD). In the proposed scheme, the transmission power of each cross-polarized channel is controlled so that it is proportional to the instantaneous received signal power of the cross-polarized channel measured at each polarized branch of a receiver. It is shown by computer simulation that the required average signal energy per bit-to-noise power spectrum density ratio (E_b/N_0) at the bit error rate of 10⁻³ using the proposed method is reduced by approximately 1 dB compared to that of the conventional polarization diversity without using transmission power control in MIMO-OFDM radio access.

I. INTRODUCTION

For dealing with the rapid increase of the demands on data services, a broadband approach to the air interface is a promising method to provide high-data-rate and high-quality services at low cost for future mobile communications beyond 3G systems. In broadband multipath fading channels, an increasing attention has been paid to orthogonal frequency division multiplexing (OFDM) based radio access as a promising modulation technique in the downlink for the systems beyond IMT-2000[1,2], since OFDM can mitigate the degradation due to severe multipath interference in a broadband channel by using many low symbol-rate sub-carriers.

Furthermore, to achieve higher capacity and quality in a radio link, the utilization of multiple-input multiple-output (MIMO) techniques have been extensively studied [3,4]. MIMO techniques utilize multiple antennas at both ends of a radio link without using additional frequency and time resources. Especially, MIMO diversity technique (e.g., space-time block coding (STBC)) is considered as an effective way to reduce the required signal energy per bit-to-noise power spectrum density ratio (E_b/N_0) [5, 6]. MIMO diversity techniques introduce temporal and spatial correlation into signals transmitted from different antennas. By utilizing the full diversity effect of transmit and receive antennas, MIMO diversity can achieve further increase in the capacity.

In general, MIMO diversity techniques have been designed to use space diversity employing only one polarization. Space diversity can yield significant diversity gain by the average effect of the received signal power of each receiver branch. However, sufficient antenna spacing is required so that the fading correlation between antenna branches is small enough to provide the full space diversity gain. For example, it is reported in [7] that antenna spacing of at least half a wavelength λ at the subscriber unit and 30 λ at the base station is required. Unfortunately, large antenna spacing increases the size of the base station and renders the utilization of multiple antennas at the subscriber unit very difficult.

On the other hand, polarization diversity employing both vertical and horizontal polarizations can make the fading correlation between co-polarized and cross-polarized channels sufficiently low regardless of antenna spacing. Consequently, by employing one dual-polarized antenna, it is possible to construct two-branch diversity. This solution does not create any restriction on antenna location. However, the diversity gain employing polarization diversity is reduced by cross polarization discrimination (XPD), which is defined as the average received power level difference between co-polarized and cross-polarized channels. If the XPD is increased, the average received power of the cross-coupled channels is decreased, and thus, the required transmit E_b/N_0 is increased compared to that with space diversity [8].

In this paper, an adaptive transmission power control for MIMO diversity employing polarization diversity in OFDM is proposed to mitigate the degradation due to the effect of XPD. In the proposed scheme, the transmission power of channels from each polarized transmitter branch is controlled adaptively to be proportional to the instantaneous received signal power of the channel, which is measured at each polarized receiver branch. In the proposed scheme, the channel quality information of the measured instantaneous received signal power at the receiver is fed back to the transmitter, and the transmission power of each polarized transmitter branch is controlled adaptively based on the feedback information. By exploiting channels from one polarized transmitter branch with more power, we can mitigate the degradation due to effect of XPD.

II. PROBLEM OF MIMO DIVERSITY EMPLOYING POLARIZATION DIVERSITY

The effectiveness of MIMO techniques strongly depends on transceiver antenna configuration such as height and spacing, and the scattering environment. However, antenna spacing of tens of wavelengths at the base station, and at least half a wavelength at the subscriber unit are usually required in order to achieve significant diversity gain. Space limitations might compromise the utilization of spatially extended arrays. The employment of polarization diversity through dual-polarized antennas instead of the traditionally used space diversity may be a promising and space-effective alternative, where two spatially separated uni-polarized antennas are replaced by a single antenna employing two orthogonal polarizations.

However, when polarization diversity is employed, depolarization caused due to scatters and imperfect antenna design might result in gain imbalance. The MIMO diversity employing polarization diversity is shown in Fig.1, T_V and T_H represent the



Figure 1 MIMO diversity employing polarization diversity

transmitter branch of vertical polarization and horizontal polarization, respectively, and R_V and R_H represent the receiver branch of vertical polarization and horizontal polarization, respectively. The term, $\xi_{p,q}$ (where *p* and *q* are either V or H, denotes the complex channel gain of each MIMO channel with polarization. The depolarization mechanisms are characterized by XPD, which is defined the average power of co-polarized channel relative to the average power of cross-coupled channel as

$$XPD = \frac{E[powerof \ co-polarized channe]}{E[powerof \ cross-polarized channe]} = \frac{E[\xi_{V,V}, \xi_{H,H}]}{E[\xi_{V,H}, \xi_{H,V}]}$$
(1)

where E[i,j] is the expectation operator of *i* and *j*. When the value of XPD is large, diversity gain between paths through different polarization is always unequal. Consequently, the available diversity gain of MIMO diversity employing polarization diversity is decreased..

III. PROPOSED ADAPTIVE TRANSMISSION POWER CONTROL FOR MIMO DIVERSITY EMPLOYING POLARIZATION DIVERSITY IN OFDM RADIO ACCESS

The available diversity gain of MIMO diversity employing polarized diversity becomes small as the average power of cross coupled branches decreases due to XPD. To solve this problem, we propose an adaptive transmission power control scheme which allocates the transmission power resource of each polarized transmitter branch based on the concept of water-filling method [10] which can increase the channel capacity. The proposed scheme actively exploits the channel from one polarized transmitter branch with more power level than the channel from the other polarized transmitter branch at the receiver. Figure 2 shows the transmitter and receiver of OFDM radio access using the proposed adaptive transmission power control for MIMO diversity employing polarization diversity, where transmission power control is adaptively done based on the received power level of each polarization branch.

Here, we assume that one packet frame with the length of 0.489 msec consists of Nframe = 64 OFDM symbols, which are comprised of 60 data symbols and four time-multiplexed pilot symbols. The transmitted signal from the p-th (p = 1, 2: p = 1 is vertical polarized transmitter branch, p = 2 is horizontal polarized transmitter branch) branch is expressed as

$$s_{p}(t) = \sum_{k=1}^{N_{gab}} P_{p,k}(n) d_{p,k}(nN_{frame} + b)$$

$$\cdot e^{j2\pi k (t-T_{g} - (nN_{frame} + b - 1)T_{g})/T_{d}}$$

$$\cdot u(t - (nN_{frame} + b - 1)T_{g})$$
(2)



(a) Transmitter



(b) Receiver Figure 2. Transmitter and receiver using the proposed adaptive transmission power control for MIMO diversity employing polarization diversity

where Nsub is the number of sub-carriers, Pp,k and dp,k are the gain and the pilot or data symbol on the k-th sub-carrier $(1 \le k \le Nsub)$ in the n-th (n: integer) packet frame from the p-th transmitter branch. Furthermore, Ts, Td, Tg are the OFDM symbol duration, effective data symbol duration, and guard interval duration, respectively (Ts = Tg + Td). The term u(t) is the unit function defined within the duration of [0,Ts], and dp,k (nNframe + b) is given by

$$d_{p,k}(nN_{frame} + b) = \begin{cases} d_{p,pilot}(b) & \text{for } 1 \le b \le 4 \\ d_{p,data,k}(nN_{frame} + b) & \text{for } 5 \le b \le N_{frame} \end{cases}$$
(3)

where dp,pilot(b) is the time-multiplexed orthogonal pilot symbol sequence, which is made of Walsh-Hadamard code, and it is a unique sequence at each transmitter branch. The term dp,data,k (nNframe + b) is the data symbol sequence, encoded by STBC in order to achieve transmit diversity between cross-polarized transmitter branches, and described as

$$d_{p,data,k}(nN_{frame}+b) = \begin{cases} d_k(nN_{frame}+b-4) \\ \text{for } p = 0 \\ -d_k^*(nN_{frame}+b-3) \\ \text{for } p = 1, \text{ when } b \text{ is odd number} \\ d_k^*(nN_{frame}+b-4) \\ \text{for } p = 1, \text{ when } b \text{ is even number} \end{cases}$$

where * denotes the complex conjugate. We assumed STBC with the coding rate of R = 1 by Alamouti [5] in the paper.

The received signal at the q-th receiver branch (q = 1, 2: q = 1 is vertical polarized receiver branch, q = 2 is horizontal polarized receiver branch), yq(t), is represented as

$$y_{q}(t) = \sum_{p=1}^{N_{t}} \sum_{l=1}^{L} f_{p,q,l}(t) s_{p}(t-\tau_{l}) + n_{q}(t)$$
(5)

where fp,q,l(t) is the complex channel gain of the l-th path $(1 \le 1 \le L)$: L is the number of paths) between the p-th transmitter branch and q-th receiver branch, τI is the time delay of the l-th path, and nq(t) is additive white Gaussian noise. The OFDM signal after fast Fourier transform (FFT) processing at the k-th sub-carrier is expressed as

$$\hat{d}_{q,k}(nN_{frame} + b) = \sum_{p=1}^{N_t} \xi_{p,q,k}(n) d_{p,k}(nN_{frame} + b) + n_{q,k}(nN_{frame} + b)$$
(6)

where ζ p,q,k,(n) is the complex channel gain at the k-th subcarrier and it is assumed to constant over one packet frame. Term nq,k (nNframe + b) is the noise component at the k-th sub-carrier of the q-th branch.

The channel estimate of the n-th frame at the k-th sub-carrier between the p-th transmitter branch and q-th receiver branch is coherently averaged over the twelve pilot symbols of the three adjacent sub-carriers with sub-carrier k as the center [11], which is represented as

$$\hat{\xi}_{p,q,k}(n) = \frac{1}{12} \sum_{k'=k-1}^{k+1} \sum_{b=1}^{4} \hat{d}_{q,k'}(nN_{frame} + b) d^*_{p,pilot}(b)$$
(7)

This channel estimate is used in the demodulation of data and feedback channel quality information for the purpose of controlling the transmission power adaptively. Then, the estimate of the channel matrix for k-th sub-carrier with the aid of pilot symbols, \vec{r}

 $\hat{\mathbf{H}}_{k}(n)$ is expressed as

$$\hat{\mathbf{H}}_{k}(n) = \begin{bmatrix} \widetilde{\xi}_{0,0,k}(n) & \widetilde{\xi}_{0,1,k}(n) \\ \widetilde{\xi}_{1,0,k}(n) & \widetilde{\xi}_{1,1,k}(n) \end{bmatrix}$$
(8)

By employing the calculated channel estimate, the demodulation of STBC is expressed as

$$\widetilde{d}_{k}(nN_{frame} + b) = \begin{cases} \sum_{q=0}^{1} \widetilde{\xi}_{0,q,k}(n) \hat{d}_{q,k}(nN_{frame} + b + 4) \\ + \widetilde{\xi}_{1,q,k}(n) \hat{d}_{q,k}^{*}(nN_{frame} + b + 5) \\ \text{when } b \text{ is odd number} \end{cases} \\ \begin{cases} \sum_{q=0}^{1} - \widetilde{\xi}_{1,q,k}(n) \hat{d}_{q,k}^{*}(nN_{frame} + b + 3) \\ + \widetilde{\xi}_{0,q,k}^{*}(n) \hat{d}_{q,k}(nN_{frame} + b + 4) \\ \text{when } b \text{ is even number} \end{cases}$$

Next, the operation of the proposed transmission power control is described. The receiver sends the feedback information of the instantaneous received power of the channel from each polarization transmitter branch by summarizing the channel gains at each polarization receiver branch based on $\mathbf{\hat{H}}_{\perp}(n)$, to the transmitter. At the transmitter, the transmission power of each polarization branch is controlled in proportional to the feedback information, which is normalized by the total transmission power. Specifically, the transmission power of the (n+1)-th frame is defined as

$$\begin{cases} P_{1,k}(n+1) = \frac{\left(\left|\hat{\xi}_{1,1,k}(n)\right|^{2} + \left|\hat{\xi}_{1,2,k}(n)\right|^{2}\right) / P_{1,k}(n)}{\alpha} P_{total} \\ P_{2,k}(n+1) = \frac{\left(\left|\hat{\xi}_{2,2,k}(n)\right|^{2} + \left|\hat{\xi}_{2,1,k}(n)\right|^{2}\right) / P_{2,k}(n)}{\alpha} P_{total} \end{cases}$$
(10)

where α is represented as

$$\alpha = \frac{\left(\left|\hat{\xi}_{1,1,k}(n)\right|^{2} + \left|\hat{\xi}_{1,2,k}(n)\right|^{2}\right)}{P_{1,k}(n)} + \frac{\left(\left|\hat{\xi}_{2,1,k}(n)\right|^{2} + \left|\hat{\xi}_{2,2,k}(n)\right|^{2}\right)}{P_{2,k}(n)}$$
(11)

Here, we assume that the total transmission power of two polarization transmitter branches is constant. Consequently, by allocating the transmission power of each polarized transmitter branch in proportion to the instantaneous received signal power of the channel measured at each polarized branch of a receiver at the transmitter, the proposed scheme can improve the BER performance.

On the other hand, the transmission power control scheme which controls the transmission power of each polarized branch in order to equalize the instantaneous received power between co-polarized and cross-polarized channels is also considered as a referenced scheme. The transmission power of the (n+1)-th frame in the referenced scheme is defined as

$$P_{0,k}(n+1) = \frac{\left(\left|\hat{\xi}_{1,1,k}(n)\right|^{2} + \left|\hat{\xi}_{1,0,k}(n)\right|^{2}\right) / P_{1,k}(n)}{\alpha} P_{total}$$

$$P_{1,k}(n+1) = \frac{\left(\left|\hat{\xi}_{0,0,k}(n)\right|^{2} + \left|\hat{\xi}_{0,1,k}(n)\right|^{2}\right) / P_{0,k}(n)}{\alpha} P_{total}$$
(12)

IV. SIMULATION CONFIGURATION

Table 1 shows the parameters used for the subsequent simulation evaluation. Here, OFDM radio access with an 80-MHz bandwidth is assumed. Furthermore, the number of transmitter/receiver branches is 2-by-1 MISO diversity (transmitter branches: vertical/horizontal polarization, receiver branch: vertical polarization) or 2-by-2 MIMO diversity (transmitter/receiver branches: vertical/horizontal polarization). At the transmitter, information bit sequence is data-modulated with BPSK. After serial-to-parallel conversion into 512 streams corresponding to the number of sub-carriers, the symbol sequence is encoded by STBC. Furthermore, the four orthogonal pilot symbols are timemultiplexed to the STBC encoded data symbols. In the proposed scheme, the calculated weights based on the feedback information are multiplexed and the overall transmission power is set to be constant. Then, the STBC encoded symbol sequence is converted into OFDM signals with Nsub = 512 sub-carriers whose 512-sample duration is 6.4 μ sec using the inverse fast Fourier transform (IFFT). In order to avoid inter-symbol interference caused by multipath propagation, a guard interval whose 100sample duration is $1.25 \,\mu$ sec is inserted between OFDM symbols. The resultant frame consists of 60 OFDM data symbols and four pilot symbols (i.e., Nframe = 64).

Table1. Sim	ulator parameters

	1
Bandwidth	80 MHz
Number of sub-carriers	512
Sub-carrier separation	156.25 kHz
OFDM symbol duration	6.4 µsec + GI 1.25 µsec
Frame length	0.489 msec
Frame structure	60 data symbol + 4 pilot symbol
Modulation	BPSK
Channel coding / decoding	STBC
Number of transmit/receive	$N_{TX} = 2, N_{RX} = 1, 2$
antenna	
Symbol timing detection	Ideal



Figure 3 Channel model

At the receiver, ideal OFDM symbol timing (i.e., FFT window timing) detection is assumed. After the guard interval is removed, the OFDM signal is de-multiplexed into each sub-carrier component by the 512-point FFT. The channel gain of each sub-carrier is estimated with the aid of the orthogonal pilot symbols. After decoded by STBC with the channel estimate at each receiver branch, each sub-carrier component is demodulated to recover the transmitted information bit sequence.

Figure 3 shows the channel model in this simulation. It is assumed that channel model is an exponential decay model with an L-path Rayleigh fading profile and the fading maximum Doppler frequency of $f_D = 10$ Hz, in which the average signal power is reduced by 12/L dB in descending order starting from the first path. Furthermore, in this simulation, the average received power level difference between co-polarized and cross-polarized channels is considered as the average XPD, and the fading correlation between transmitter/receiver polarized branches is assumed to be $\chi = 0$ due to the employment of a polarized antenna.

V. SIMULATION RESULTS

Figures 4 (a) and (b) show the average BER performance employing the proposed adaptive transmission power control in MIMO diversity as a function of the average transmit Eb/N0 in the case of one receiver branch (vertical polarization, NRX =1) and two receiver branches (vertical/horizontal polarization, NRX =2), respectively, with the value of XPD, χ = 0 and 6 dB. Note that we define transmit E_b/N_0 as the ratio between the transmitted signal energy per bit to noise power spectrum density at the receiver. The BER performance employing the referenced scheme that controls the transmission power of each polarized branch in order to equalize the instantaneous received power level between the channels from cross-polarized transmitter branch in MIMO diversity is plotted. We also show the BER performance of MIMO diversity without transmission power control for comparison. The path model is set to be an exponential delay model with a six-path Rayleigh fading, the r.m.s. delay spread is set to $\sigma = 0.16 \ \mu$ sec, and the maximum Doppler frequency is set to $f_D = 10$ Hz. It is shown from Fig. 4 that the average BER performance of the proposed scheme is improved compared with that of the referenced scheme and the scheme without transmission power control, regardless of the number of receiver antenna branches and the average XPD. For instance, in the case of NRX = 2, the required average transmit E_b/N_0 at the BER of 10^{-3} of the proposed scheme is improved by approximately 1 dB compared with the scheme without transmission power control. These results indicate that the proposed scheme can allocate more transmission power for one polarized transmitter branch which brings about more power level at the receiver effectively, although the diversity gain is reduced due to the unequally aver



(b) Two receiver branches Figure 4. Average BER performance of the propose scheme, the referenced scheme, and the scheme without transmission power control (TPC).

age received signal power level between co-polarized and crosspolarized channels. On the other hand, the BER performance of the referenced scheme is degraded considerably compared with the scheme without transmission power control. This is because the referenced scheme controls the transmission power of each polarized branch in order to equalize the instantaneous received signal power level between co-polarized and cross-polarized channels. This renders the referenced scheme allotting more transmission power to one polarized branch, which is more severely deteriorated by the deep fading, when the difference of the received signal power levels between the channels from each polarized transmitter branch is large. Consequently, under the conditions of the fixed constant transmission power between two branches, the overall received power level is decreased, and thus, the BER performance of the referenced scheme is degraded.

Figures 5 (a) and (b) show the required average required transmit E_b/N_0 for satisfying the average BER of 10^{-3} as a function of

the average XPD in the case of NRX = 1 and NRX = 2, respectively. The other simulation conditions such as the path model are identical to those in Fig.4 As shown in Fig.5, by employing the proposed scheme in the case of NRX = 1 and NRX =2, the average required transmit E_b/N_0 is reduced by approximately 0.5 to 1 dB and 0.5 to 1 dB, respectively, compared to the conventional scheme without transmission power control



(b) Two receiver branches Figure 5 Required average transmit E_b/N₀ for satisfying the average BER of 10⁻³ as a function of the average XPD

assuming the value of XPD 0 to 15 dB. The figure also shows that according to the increase in the XPD value, the effect of reducing the transmit E_b/N_0 is slightly increased. This is because the received signal power level of the co-polarized channel is dominant in controlling the transmission power due to a decrease in the component of the cross-polarized channels in Eq.(11), and thus, the gain of the co-polarized channels only reflects on controlling the transmission power. This increases the effectiveness of the proposed transmission power control. Furthermore, the required transmit E_b/N_0 of the proposed scheme in MIMO diversity without a transmission power control employing space diversity in the case of both $N_{RX} = 1$ and $N_{RX} = 2$ with below $\chi = 4$ dB. On the other hand, the required transmit E_b/N_0 of the conventional scheme re-

gardless of XPD values by the decrease in the received power level due to equalization of the instantaneous received power between co-polarized and cross-polarized channels. Especially, in the case of $N_{RX} = 1$, the performance degradation is increased according to the increase in the XPD value.

IV. CONCLUSION

We have proposed an adaptive transmission power control scheme between cross-polarized transmitter antennas for MIMO diversity employing polarization diversity in OFDM radio access in order to reduce the required transmit E_b/N_0 to compensate for the degradation of XPD. It is shown by simulation results that the required average transmit E_b/N_0 at the average BER of 10^{-3} using the proposed scheme is reduced by approximately 1 dB compared to that of the conventional polarization diversity without transmission power control in MIMO-OFDM radio access. It is also shown that the required transmit E_b/N_0 of the proposed scheme is the same or reduced than that of the MIMO diversity without transmission power control employing space diversity in the case of both $N_{RX} = 1$ and $N_{RX} = 2$ with the XPD value of less than 4dB.

ACKNOWLEDGMENT

This work is partly supported by Keio University 21st Century Center of Excellence Program on "Optical and Electronic Device Technology for Access network", selected by the Ministry of Education, Culture, Sport, Science and Technology, Japan.

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