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Novel Channel Estimation and Compensation schemes for Massive MIMO-OFDM

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Abstract—Since the number of pilot symbols is proportionally depending on the number of transmit antennas, the total transmission rate of massive MIMO would be degraded. To solve this problem, high time resolution carrier interferometry for MIMO/OFDM (HTRCI-MIMO/OFDM) has been proposed. HTRCI-MIMO systems use a few pilot symbols. Moreover, channel compensation using virtual pilot signal (VPS) has been proposed. However, the number of pilot signals with HTRCI-MIMO is not enough for massive MIMO. Since the conventional VPS method iteratively identifies the channel state information (CSI), the complexity is considerable work and the method has low accuracy. From the simulation results, the BER performance of the proposed scheme achieves 2 ∼ 2.5dB gains compared with the conventional method based on Hadamard code in 8×8 and 16×16 MIMO. Moreover, the throughput performance of the proposed scheme achieves 30 ∼ 53% improvement compared with the conventional method based on Hadamard code.

1. Introduction

With the spread of mobile network, wireless communications are indispensable in our life. In Japan, 4th Generation mobile communication systems (4G) such as WiMAX2 (Worldwide Interoperability for Microwave Access 2) [1] and LTE-Advanced (Long Term Evolution-Advanced) [2] have been widely used. On the other hand, a variety of novel techniques has been proposed to put it to practical use for 5th Generation mobile communication systems (5G) recently [3]. Since communication frequency band has been tight in recent years, it is necessary to increase band utilization efficiency for 5G. Therefore, high frequency band usage is widely studied for implementation of 5G. Thus, massive MIMO has been widely studied [4]. At present, a wireless LAN has been established a standard up to 8 × 8 MIMO [5]. Furthermore, massive MIMO is considering to use about 100 antennas. Since the number of pilot symbols is proportionally depending on the number of transmit antennas, the total transmission rate of MIMO system would be degraded because the pilot symbol does not carry any information. To solve this problem, high time resolution carrier interferometry for MIMO/OFDM (HTRCI-MIMO/OFDM) [6] has been proposed. HTRCI-MIMO system has a good BER performance with a few number of pilot symbols. Moreover, channel compensation using virtual pilot signal (VPS) has been proposed [7] [8] [9]. VPS method compensates for data signals with CSI. However, the number of pilot symbols is half as many as Hadamard code in HTRCI-MIMO system. It is not enough for massive MIMO. Since the conventional VPS method iteratively identifies the CSI, the complexity and low estimation accuracy are considerable work. To reduce the number of pilot symbols and complexity, we propose a novel HTRCI-MIMO with modified orthogonalization method and VPS. This paper is organized as follows. We show the channel model and iterative identification based on VPS in Section 2. In Section 3, we show the proposed schemes. In Section 4, we show the simulation results. Finally, we describe the conclusion in Section 5.

2. System Model

2.1. Channel model

The propagation channel consists of L discrete paths with different time delays, is assumed. The impulse response between the xth transmit and the yth receive antenna $h_{x,y}(\tau, t)$ is expressed as

$$h_{x,y}(\tau, t) = \sum_{l=0}^{L-1} h_{x,y,l}(t)\delta(\tau - \tau_{x,y,l}), \tag{1}$$

where $h_{x,y,l}$ is the complex channel gain and $\tau_{x,y,l}$ is the time delay of the lth path. $H_{x,y}(f, t)$ is the channel transfer function and the Fourier transform of $h_{x,y}(\tau, t)$. Then, the channel transfer function $H_{x,y}(f, t)$ is given by

$$\begin{aligned} H_{x,y}(f, t) &= \int_0^{\infty} h_{x,y}(\tau, t)e^{-j2\pi f\tau}d\tau \\ &= \sum_{l=0}^{L-1} h_{x,y,l}(t)e^{-j2\pi f\tau_{x,y,l}}. \end{aligned} \tag{2}$$

2.2. Conventional identification based on VPS

Firstly, the transmitter sends the data signals with forward error correcting code (FEC). In the receiver, the received data signals are demodulated. After decoding, the data signals are obtained. Next, the receiver generates the replica signals $\tilde{d}$ using decoded data signals. The channel variance $\Delta H^1_{x,y}(k)$ of the xth transmit antenna, the yth receive antenna, the kth subcarrier and the first iteration using VPS in MIMO system is expressed as

$$\begin{aligned} \Delta H^1_{x,y}(k) = &\sum_{i=0}^{N_S-1} \sum_{n=0}^{X-1} \\ &\frac{r_y(k, i) - \tilde{H}_{n,y}(k)\tilde{d}_n(k, i)}{\tilde{H}_{x,y}(k)\tilde{d}_x(k, i)N_S} + 1, \end{aligned} \tag{3}$$

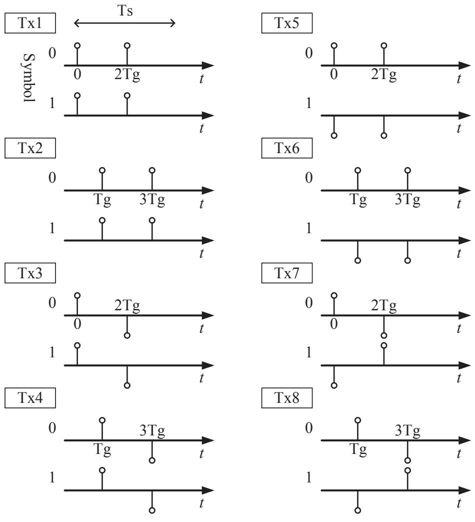

Figure 1: Pilot signal on time domain in 8 × 8 MIMO

where $\tilde{H}_{n,y}(k)$ is an initially estimated channel response, $\tilde{d}_n(k,i)$ is the transmitted signal, $r_y(k,i)$ is the received signal, X is the number of transmit antennas and N_S is the number of data symbols with the channel re-identification. Therefore, the adjusted channel response $\tilde{H}^1_{x,y}(k)$ of the first iteration is given by

$$\tilde{H}^1_{x,y}(k) = \Delta H^1_{x,y}(k)\tilde{H}_{x,y}(k). \tag{4}$$

With the ξ time iterations, the adjusted channel response can be obtained by,

$$\tilde{H}^{\xi}_{x,y}(k) = \Delta H^{\xi-1}_{x,y}(k)\tilde{H}^{\xi-1}_{x,y}(k). \tag{5}$$

To prevent the performance deterioration due to the fast channel variance, the following condition is also considered as

$$\hat{H}_{x,y}(k) = \begin{cases} \tilde{H}^{\xi}_{x,y}(k) & \frac{|\tilde{H}^{\xi}_{x,y}(k)|^2}{|\tilde{H}^{\xi-1}_{x,y}(k)|^2} \geq \zeta \\ \tilde{H}^{\xi-1}_{x,y}(k) & \text{otherwise} \end{cases}, \tag{6}$$

where ζ ($0 \leq \zeta \leq 1$) is the threshold. By using this threshold, we prevent the deterioration of BER performance. Here, we choose the threshold ζ using the simulation results [8]. Since we execute iteratively the identification, the channel compensation is accurately operated. As we mentioned above, the total transmission rate of massive MIMO would be degraded with the orthogonal pilot based channel estimation scheme. Moreover, the conventional VPS method is not suitable for massive MIMO since the method identifies the CSI with iterative detection. Therefore, the complexity is also increased.

3. Proposed channel estimation and compensation

In this section, we propose a novel scheme with HTRCI-MIMO with modified orthogonalization methods and VPS method. Since massive MIMO systems use high frequency band, the communications area should be small. In other words, multipath delay spread is short and desired signals are concentrated in a portion. Therefore, when we can easily identify the CSI on the time domain. Moreover, since the proposed scheme uses the initially estimated CSI using VPS, we can reduce the complexity. In the conventional HTRCI-MIMO system, the transmitted pilot signal $d_{ps,x}(k,p)$ of the xth transmit antenna, the kth subcarrier and pth symbol is given by

$$d_{ps,x}(k,p) = \begin{cases} M_{x,2}|W_k| + M_{x+1,2}W_k & \text{for } p = \lceil \frac{x}{2} \rceil \\ 0 & \text{otherwise} \end{cases}, \tag{7}$$

where $M_{a,b} = \mathrm{mod}(a,b)$, $W_k = \frac{i^k + (-i)^k}{2}$, $0 \leq p \leq N_p - 1$, N_p is the number of pilot symbols and $\lceil x \rceil$ stands for the integer upper and closer to x. Since the impulse responses are not overlap to each other in the time domain, we can separate the received pilot signals in each receive antenna. In this paper, we reduce the number of pilot symbols using HTRCI-MIMO with modified orthogonalization method. In the novel scheme, the transmitted pilot signal is given by

$$\begin{aligned} &d_{ps,x}(k,p) \\ &= \begin{cases} \lfloor \frac{M_{x,4}}{3} \rfloor |W_{k+1}| + \lfloor \frac{M_{x+1,4}}{3} \rfloor W_k + \lfloor \frac{M_{x+2,4}}{3} \rfloor |W_k| + \lfloor \frac{M_{x+3,4}}{3} \rfloor W'_k \\ \quad \text{for } \lceil \frac{x}{4} \rceil = \text{odd and } \lceil \frac{x}{4} \rceil - 1 \leq p \leq \lceil \frac{x}{4} \rceil \\ (-1)^p (\lfloor \frac{M_{x,4}}{3} \rfloor |W_{k+1}| + \lfloor \frac{M_{x+1,4}}{3} \rfloor W_k \\ \qquad + \lfloor \frac{M_{x+2,4}}{3} \rfloor |W_k| + \lfloor \frac{M_{x+3,4}}{3} \rfloor W'_k) \\ \quad \text{for } \lceil \frac{x}{4} \rceil = \text{even and } \lceil \frac{x}{4} \rceil - 2 \leq p \leq \lceil \frac{x}{4} \rceil - 1 \\ 0 \quad \text{otherwise} \end{cases}, \end{aligned} \tag{8}$$

where $\lfloor x \rfloor$ stands for the integer lower and closer to x and $W'_k = \frac{(-i)^k - i^k}{2}$. Fig.1 shows pilot signal on the time domain. The figure shows the number of pilot symbols is quarter as many as Hadamard code. The received impulse responses are multiplexed without interference because the transmitted pilot signals are orthogonalized by Hadamard code. Therefore, the received impulse responses are given by

$$\begin{aligned} &h_y(p) \\ &= \begin{cases} \sum_{n=0}^{\frac{X}{2}-1} (-1)^{\lceil \frac{p}{2} \rceil \lfloor \frac{n}{2} \rfloor} h_{2n+1,y} \\ \quad \text{for } \ t = [0, T_g - 1] \text{ and } \lceil \frac{n+1}{4} \rceil - 1 \leq p \leq \lceil \frac{n+1}{4} \rceil \\ \sum_{n=0}^{\frac{X}{2}-1} (-1)^{\lceil \frac{p}{2} \rceil \lfloor \frac{n}{2} \rfloor} h_{2(n+1),y} \\ \quad \text{for } \ t = [T_g, 2T_g - 1] \text{ and } \lceil \frac{n+1}{4} \rceil - 1 \leq p \leq \lceil \frac{n+1}{4} \rceil \\ \sum_{n=0}^{\frac{X}{2}-1} (-1)^{\lceil \frac{p}{2} \rceil \{\lfloor \frac{M_{2n+1,4}}{3} \rfloor + \lfloor \frac{M_{2(n+1),4}}{3} \rfloor\}} h_{2n+1,y} \\ \quad \text{for } \ t = [2T_g, 3T_g - 1] \text{ and } \lceil \frac{n+1}{4} \rceil - 1 \leq p \leq \lceil \frac{n+1}{4} \rceil \\ \sum_{n=0}^{\frac{X}{2}-1} (-1)^{\lceil \frac{p}{2} \rceil \{\lfloor M_{2n+1,4} \rfloor + \lfloor M_{2(n+1),4} \rfloor\}} h_{2(n+1),y} \\ \quad \text{for } \ t = [3T_g, T_s - 1] \text{ and } \lceil \frac{n+1}{4} \rceil - 1 \leq p \leq \lceil \frac{n+1}{4} \rceil \\ 0 \ \text{ for } \ \text{otherwise} \end{cases}, \end{aligned} \tag{9}$$

where T_g is the guard interval (GI) length and T_s is the effective symbol length. We assume $T_g = \frac{T_s}{4}$ in this paper.

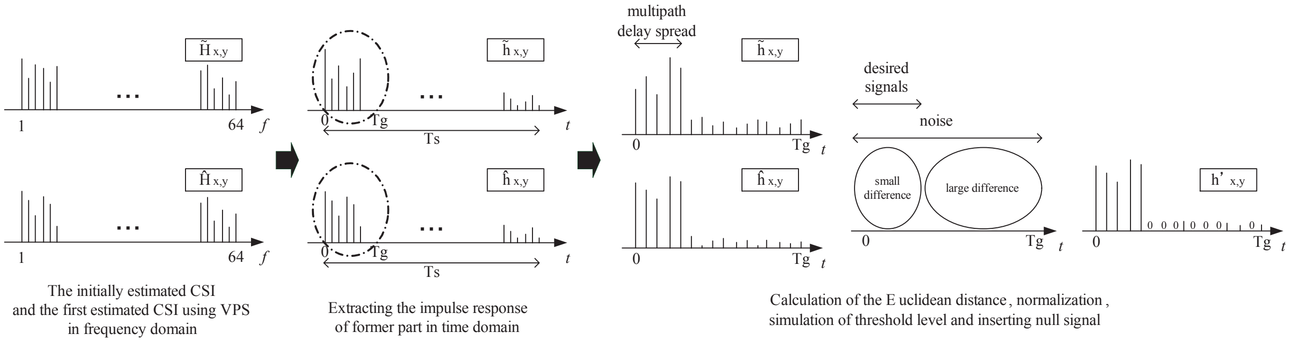

Figure 2: The concept of proposed noise whitening

Therefore, we can separate these signals into each transmitted signal. Since the power of pilot signals is half of orthogonal pilot signal based on Hadamard code, the channel response is highly affected by the noise. Meanwhile, since we separate four portions of channel responses, we can averaging to reduce the noise effect. After the pilot signal separation, we operate the same procedure as the conventional HTRCI-MIMO. Fig.2 shows the concept of proposed noise whitening. Firstly, we use the initially estimated CSI ($\tilde{H}_{x,y}$) and first estimated CSI using VPS ($\hat{H}_{x,y}$). By applying the IFFT operation, we obtain the time signals. Next, we extract the impulse response of former part ($t = [0, T_g - 1]$). After that, we calculate the Euclidean distance of each impulse response and normalize the distance. Since multipath delay spread is small, the Euclidean distances of the desired impulse responses differ from other responses. In other words, the Euclidean distances of the desired response are small. To eliminate noise component, we insert null signals using threshold level. Moreover, other part ($t = [T_g, T_s - 1]$) is not contained desired impulse response. Therefor, we insert null signals in the part. Finally, we apply the FFT operation to obtain frequency responses. By using these schemes, we can obtain the improved CSI ($h'_{x,y}$).

4. Simulation Results

In this simulation, the modulation is QPSK, the detection method is ZF, FEC is the convolutional code($R_c = \frac{1}{2}$, $L_c = 7$), the number of antennas, pilot symbols and data are 8 or 16, 2 or 4 and 20, FFT size is 64, the number of subcarriers is 62, GI is 16 sample times, the channel model is 5 path Rayleigh fading and Doppler frequency is 10Hz. Fig.3 shows the simulation result to choose the optimum threshold as 0.15 and 0.10 for 8×8 and 16×16 MIMO. Fig.4 and Fig.5 show the BER performance for 8×8 and 16×16 MIMO. As the results, the proposed scheme achieves 2 ∼ 2.5dB gains compared with the orthogonal pilot based channel estimation scheme. Moreover, the BER performance of the proposed scheme is 1.5 ∼ 2dB better than the second iteration. Thus, the proposed scheme achieves good BER performance and low complexity compared with the conventional VPS method. Fig.6 and Fig.7 show the throughput performance for 8×8 and 16×16 MIMO. From the simulation results, the proposed scheme achieves 30 ∼ 53% throughput compared with the orthogonal pilot based channel estimation scheme.

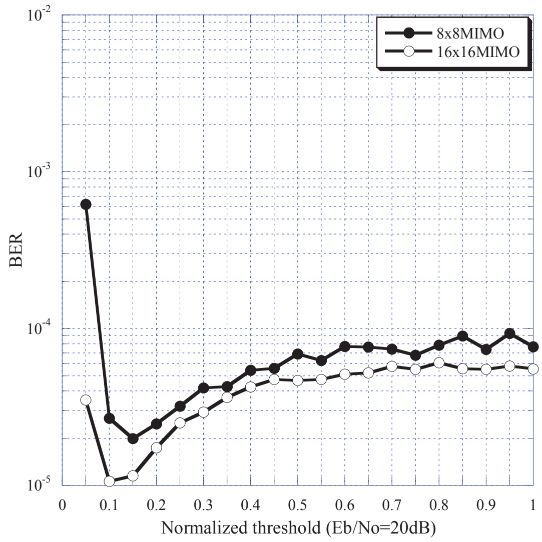

Figure 3: Normalized threshold

5. Conclusion

In this paper, we have proposed a novel scheme with HTRCI-MIMO and VPS to improve BER and throughput performance and mitigate the complexity of channel compensation. From the simulation results, it is shown that the proposed scheme achieves 2 ∼ 2.5dB gains compared with the orthogonal pilot based channel estimation scheme for 8×8 and 16×16 MIMO at BER=10^{-5}. Moreover, the proposed scheme achieves 30 ∼ 53% improvement compared with the orthogonal pilot based channel estimation scheme.

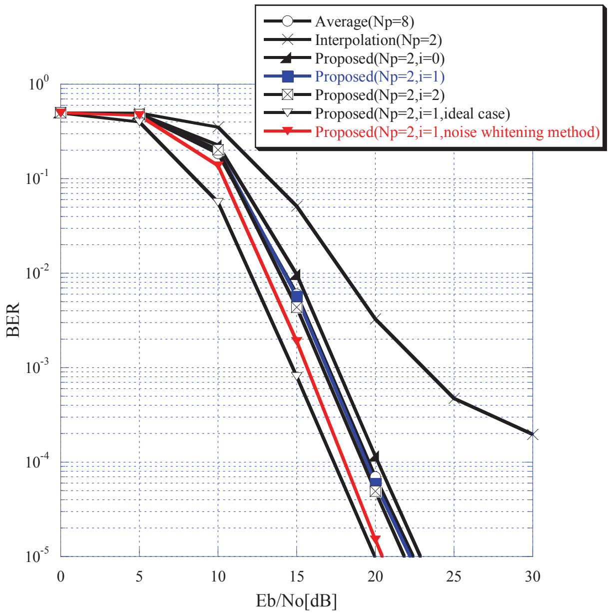

Figure 4: BER performance in 8 × 8 MIMO

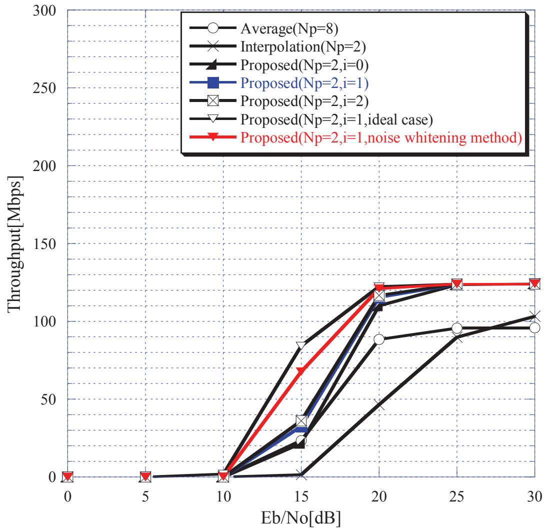

Figure 6: Throughput performance in 8 × 8 MIMO

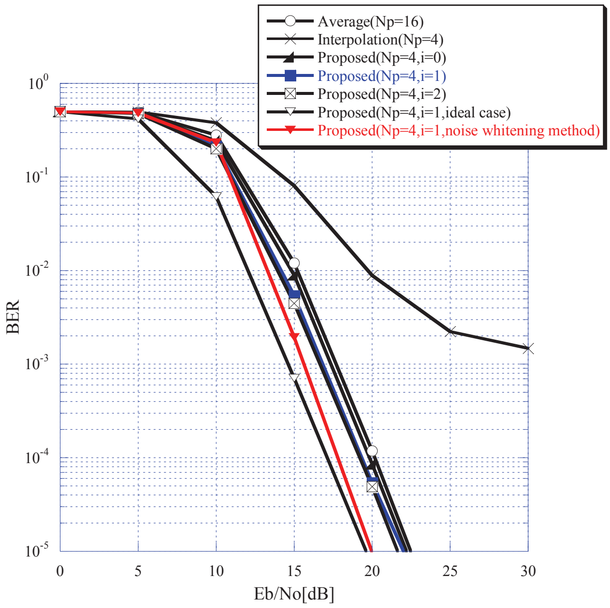

Figure 5: BER performance in 16 × 16 MIMO

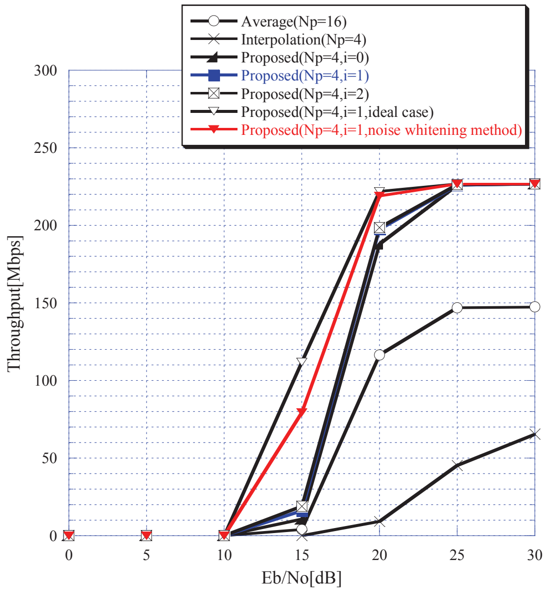

Figure 7: Throughput performance in 16 × 16 MIMO

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