2017 International Symposium on Nonlinear Theory and Its Applications,
NOLTA2017, Cancun, Mexico, December 4-7, 2017

Iterative Equalization Based on Estimated Variance and Threshold for Massive MIMO with Spatial Modulation

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Abstract—In recent years, next generation data communications called fifth generation (5G) is studied. To achieve this demand, massive multiple-input multiple-output (MIMO) systems are considered. In general, the MIMO transmissions are considered based on a space division multiplexing (SDM). However, SDM may include the interference between the signals from the different transmit antenna in the receive antenna. To solve this problem, spatial modulation (SM) has been proposed, but its performance is degraded when the detection error is occurred. Therefore, in this paper, we propose the iterative equalization based on the estimated variance and the threshold for massive MIMO systems with a SM.

1. Introduction

In recent years, next generation data communications called fifth generation (5G) is studied actively to achieve the dramatic improvement of the system performance [1]. As the technique to achieve this demand, there are the small cell, millimeter wave, cooperative, and multiple-input multiple-output (MIMO) systems [2]. MIMO and cooperative systems obtain the space diversity and improve the system performance by using several antennas and relay nodes. Especially, in MIMO systems, massive MIMO obtains the space diversity gain dramatically. Massive MIMO adapts many transmit and receive antennas compared with a normal MIMO. On the other hand, its circuit size becomes very large since massive MIMO requires many antennas and the interval between adjacent antennas. To solve this problem, massive MIMO is achieved in a high frequency such as millimeter wave techniques [3].

In MIMO systems, the signal separation is important to prevent the interference from the different transmit antenna. To achieve this demand, in general, space division multiplexing (SDM) is adopted in MIMO transmissions [4]. SDM improves the transmission rate since it transmits the different signal from the different transmit antenna. However, since SDM transmits the signal in a same time, the interference between the signals from the different transmit antenna may be occurred in the receive antenna. To solve this problem, spatial modulation (SM) has been proposed [5]. SM modulates the transmitted signal and is allocated in any transmit antenna by using the mapping table. As a result, SM prevents the interference between the signals from the different transmit antenna in the receive antenna. On the other hand, SM degrades the system performance significantly when the detection error is occurred. To solve this problem, the optimal detection for a SM has been proposed [6]. However, since [6] adapts the maximum likelihood detection (MLD), large complexity is required. Moreover, the adaptive antenna selection with a SM has been proposed [7], but the feedback for the each channel state information (CSI) and the adaptive antenna selection are required in the transmitter. Therefore, in this paper, we propose the iterative equalization based on the estimated variance and the threshold for massive MIMO systems with a SM.

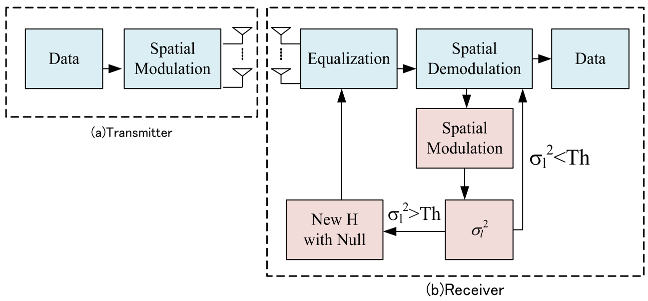

Figure 1: Block diagram of the proposed system

2. System model

In this paper, we assume that channel estimation is an ideal. Figure 1 shows the block diagram of the proposed system.

2.1. Transmitter

Fig. 1(a) shows the structure of the transmitter. Firstly, the binary data signal is generated. Next, SM is modulated the bit signal $D(i)$ based on the transmit antenna number. Table 1 shows the example of the mapping table for N_{bit} = 3, M = 4, and C = 1, where N_{bit} is the number of bit signals, M is the number of transmit antennas, and C is the modulation level. By using the mapping table as shown in Tab. 1, the SM signal for the mth transmit antenna and the

kth symbol is mapped as

$$S_m(k) = \begin{cases} S_{SM} & \text{for } a(k) = \sum_{i=0}^{N_{bit}-1} D(i) \\ 0 & \text{for otherwise,} \end{cases} \quad (1)$$

where S_{SM} is the modulation signal based on a SM, $a(k)$ is defined as

$$a(k) = \sum_{m=0}^{M-1} \sum_{c=0}^{C-1} \sum_{i=0}^{N_{bit}-1} a_{m,c,i}, \quad (2)$$

and $a_{m,c,i}$ is the reference signal for the mapping table.

2.2. Receiver

Fig. 1(b) shows the structure of the receiver. Firstly, the received signal for the nth receive antennas is given by

$$R_n(k) = \sum_{m=0}^{M-1} H_{m,n}(k) S_m(k) + Z_n(k), \quad (3)$$

where $H_{m,n}(k)$ is the channel response between the mth transmit and nth receive antennas and $Z_n(k)$ is an additive white Gaussian noise (AWGN) a signal side power spectral density of N_0. The received signal $R_n(k)$ is detected to eliminate the channel response $H_{m,n}(k)$ as

$$\hat{S}_m(k) = \max\left(\sum_{n=0}^{N-1} \sum_{m=0}^{M-1} H_{m,n}^{-1}(k) R_n(k) \right) \quad \text{for} \quad a(k) = \sum_{i=0}^{N_{bit}-1} D(i), \quad (4)$$

where N is the number of receive antennas, $(\cdot)^{-1}$ is the inverse operation, and $\max(J)$ is the maximum value of J. The detected signal $\hat{S}_m(k)$ is demodulated is returned to the bit signal in reference to the mapping table.

Table 1: Mapping table for $N_{bit} = 3$, $M = 4$, $C = 1$

Bit signal	Transit antenna number	Modulated signal
000	1	1
001	1	-1
010	2	1
011	2	-1
100	3	1
101	3	-1
110	4	1
111	4	-1

3. Proposed Iterative Equalization

3.1. Estimated Variance

By using Eq. (4), SM obtains the detected signals. However, when the detected signal is error, the burst error is occurred and the system performance is degraded. To solve this problem, the proposed method achieves the interleaved equalization based on the estimated variance and the threshold. Firstly, the proposed method gives the lth estimated variance as

$$\sigma_l^2 = \min\left(\sum_{n=0}^{N-1} \sum_{m=0}^{M-1} |R_n(k) - H_{m,n}(k)\tilde{S}_{l,m}(k)|^2 \right) \quad \text{for } 0 \le l \le M-1, \quad (5)$$

where $\min(J)$ is the minimum value of J and $\tilde{S}_{l,m}(k)$ is the lth detected signal. For the detected signal $\tilde{S}_{l,m}(k)$, when $l = 0$, we define $\tilde{S}_{0,m}(k) = \hat{S}_m(k)$. Moreover, in the next subsection, we will define the lth detected signal $\tilde{S}_{l,m}(k)$ for $l > 0$.

3.2. Proposed Iterative Equalization

After determining the estimated variance σ_l^2 from Eq. (5), the proposed method obtains the next detected signal as

$$\tilde{S}_{l,m}(k) = \begin{cases} \max\left(\sum_{n=0}^{N-1} \sum_{m=0}^{M-1} \tilde{H}_{m,n}(k) R_n(k) \right) & \text{for } \sigma_l^2 > Th \\ \tilde{S}_{l-1,m}(k) & \text{for } \sigma_l^2 \le Th, \end{cases} \quad (6)$$

where Th is the threshold. In this paper, the optimum value of Th will be decided by using computer simulation and will be shown in the next section. Moreover, $\tilde{H}_{m,n}(k)$ is the new channel response and is defined as

$$\tilde{H}_{m,n}(k) = \begin{cases} H_{m,n}(k) & \text{for } m_l \ne m \\ 0 & \text{for } m_l = m, \end{cases} \quad (7)$$

where m_l is the lth estimated transmit antenna number. Observing Eq. (6), when $\sigma_l^2 \le Th$, the estimated variance σ_l^2 outputs only the noise power as

$$\begin{aligned} \sigma_l^2 &= \min\left(\sum_{n=0}^{N-1} \sum_{m=0}^{M-1} |R_n(k) - H_{m,n}(k)\tilde{S}_{l,m}(k)|^2 \right) \\ &= \min\left(\sum_{n=0}^{N-1} \sum_{m=0}^{M-1} |Z_n(k)|^2 \right). \end{aligned} \quad (8)$$

In this case, since Eq. (8) means $\tilde{S}_m(k) = S_m(k)$, the proposed method outputs the detected signal as shown in Eq. (4). On the other hand, when $\sigma_l^2 > Th$, the estimated variance σ_l^2 outputs the interference and noise power as

$$\begin{aligned} \sigma_l^2 &= \min\left(\sum_{n=0}^{N-1} \sum_{m=0}^{M-1} |R_n(k) - H_{m,n}(k)\tilde{S}_{l,m}(k)|^2 \right) \\ &= \min\left(\sum_{n=0}^{N-1} \sum_{m=0}^{M-1} |I_{m,n}(k) + Z_n(k)|^2 \right), \end{aligned} \quad (9)$$

where $I_{m,n}(k)$ is the interference element. In this case, since Eq. (9) means $\tilde{S}_m(k) \ne S_m(k)$. Therefore, the proposed

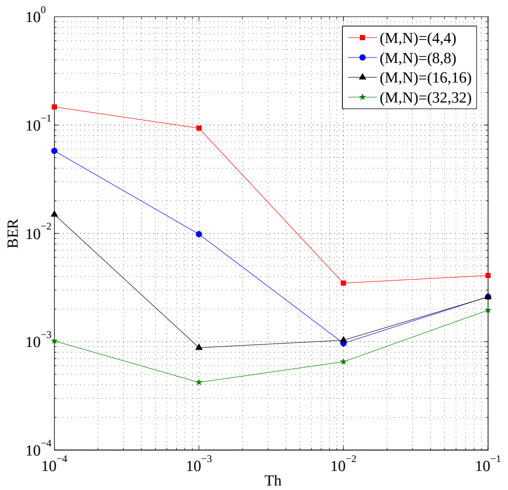

Figure 2: BER versus threshold Th at SNR = 15 dB

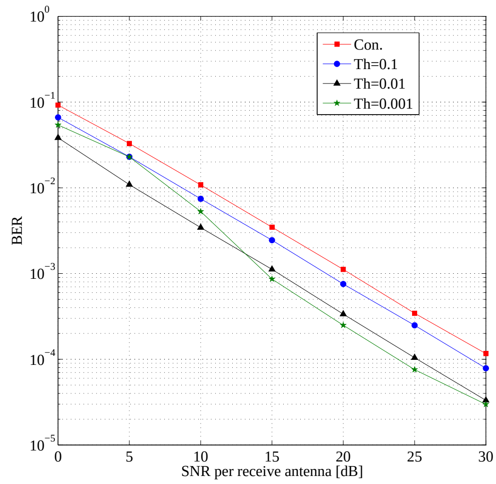

Figure 3: BER versus SNR per receive antenna for $(M, N) = (16, 16)$

method updates the channel response and is detected again by using Eqs. (6) and (7). These operations are repeated until $\sigma_l^2 \leq Th$. The complexity of the proposed method is KA^3, where A is the number of antennas for the large value between M and N, and K is number of repeat processing between $1 \leq K \leq A$. On the other hand, the proposed method suppresses the increasing of the complexity due to the repeat processing by using the estimated variance σ_l^2 and the threshold Th as shown in Eq. (6). Therefore, the proposed method obtains the more accurate detected signal by increasing little complexity.

4. Computer simulation results

Figure 1 shows the system model of proposed method and Table 2 shows the simulation parameters. In this paper, we assume the number of transmit and receive antennas as $(M, N) = (4, 4)$, $(8, 8)$, $(16, 16)$ and $(32, 32)$. In the transmitter, the original bit signal is generated and is modulated based on a SM by using the mapping table as shown in Tab. 1. SM is a binary phase shift keying (BPSK). In the propagation channel, we assume a quasi-static Rayleigh fading channel, where channel state is an ideal. In the receiver, the received signal is detected by using Eq. (4). The proposed method estimates the variance by using Eq. (5). Here, when the estimated variance is smaller than the threshold, the detected signal is output. On the other hand, when the estimated variance is greater than the threshold, the estimated variance is updated and the received signal is detected again as shown in Eqs. (5) and (6). This signal is updated until the estimated variance is smaller than the threshold. Finally, the detected signal is demodulated by using the mapping table and is returned to the bit signal.

Fig. 2 shows the bit error rate (BER) versus threshold Th at $SNR = 15$ dB, where SNR means signal to noise ratio. In $Th = 0.01$, the proposed method for $(M, N) = (4, 4)$ shows the best BER. On the other hand, the proposed method for $(M, N) = (16, 16)$ and $(32, 32)$ shows the best BER in $Th = 0.001$. This is because the diversity gain for $(M, N) = (16, 16)$ and $(32, 32)$ is a large compared with $(M, N) = (4, 4)$ and $(8, 8)$. Therefore, the accuracy of the detected signal is improved and the estimated variance is a small in $(M, N) = (16, 16)$ and $(32, 32)$.

Fig. 3 shows the BER versus SNR per receive antenna for $(M, N) = (16, 16)$. For Fig. 3, the proposed method for $Th = 0.1$ shows about 2 dB gain compared with the conventional method. This is because the proposed method adapts the iterative equalization based on the estimated variance and threshold. The proposed method for $Th = 0.01$ shows about 3 dB gain compared with the proposed method for $Th = 0.1$. This is because $Th = 0.01$ is the suitable value compared with $Th = 0.1$ in $(M, N) = (16, 16)$. The proposed method for $Th = 0.001$ shows the best performance in $SNR \geq 13$ dB. On the other hand, when $SNR < 13$ dB, the proposed method for $Th = 0.001$ shows the deterioration. This is because the proposed method mistakes the detection process due to the large noise power.

Fig. 4 shows the BER versus SNR perreceive antenna for $(M, N) = (32, 32)$. For Fig. 4, the proposed method for $Th = 0.01$ shows about 6 and 5 dB gains compared with the conventional method and the proposed method for

Table 2: Simulation parameters

Spatial modulation	BPSK
Number of antennas	$(M, N) = (4, 4), (8, 8), (16, 16), (32, 32)$
Channel model	Quasi-static Rayleigh fading
Channel state	Ideal

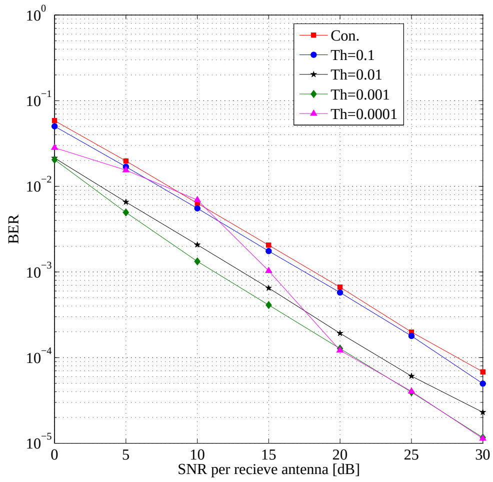

Figure 4: BER versus SNR per receive antenna for $(M, N) = (32, 32)$

$Th = 0.1$. The proposed method for $Th = 0.001$ shows the best performance in all SNR and the proposed method for $Th = 0.0001$ shows also the best performance in $SNR \geq 20$ dB. These mean that the optimum value for the threshold is different between $(M, N) = (16, 16)$ and $(32, 32)$.

5. Conclusion

In this paper, we have proposed the iterative equalization based on the estimated variance and the threshold for massive MIMO systems with a SM. The conventional SM degrades the system performance when the detection error is occured. The proposed method estimates the interference variance and achieves the iterative equalization based on the thereshold. From the computer simulation results, the proposed method has shown the good BER performance by using the iterative equalization based on the estimated variance and the optimum threshod.

Acknowledgments

This work was partly supported by JSPS KAKENHI Grant-in-Aid fro Young Scientists (B) Number 15K18065.

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