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Enhanced Simplified Maximum Likelihood Detection (ES-MLD) in Multiuser MIMO Downlink in Time-Variant Environment

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1. Introduction

In downlink multiuser MIMO (multiple input multiple output) systems, multiple beams are generated for multiple data streams to suppress inter-user interference (IUI). Since transmit beamforming requires accurate channel state information (CSI), IUI becomes a serious problem in a time variant environment [1]. In such a scenario, multiple interference signal streams are received at a mobile station (MS) and the number of signal streams may exceed the number of antenna branches at the MS. Thus, any linear beamforming at the MS cannot eliminate the interfering signal streams and as a consequence the residual interference causes significant transmission quality degradation. Although maximum likelihood detection (MLD) is the best decoding method, the calculation complexity is prohibitively high and it is difficult to implement MLD in an actual wireless access system. To reduce the calculation complexity, simplified MLD (S-MLD) was proposed in single-user scenario [2]. In S-MLD, the number of candidates of the desired signal sets is decreased through a successive detection approach and the calculation complexity level is sufficiently low for the actual hardware while a performance level comparable to that for full MLD is maintained. However, the performance of S-MLD is vulnerable to unexpected interference, and the improvement in transmission quality is limited in a time variant environment. To achieve further improvement, this paper proposes a new transmission and decoding method based on S-MLD. In the proposed enhanced S-MLD (ES-MLD) method, the dimensions of the signal path search space are expanded by adding interference signal space to the desired signal space. In ES-MLD, the orthogonal preambles for all users are transmitted. Thus, the MS can estimate the channel responses not only for the desired signals but also for the undesired signals. ES-MLD has scalability to trade off the performance and calculation complexity by varying the number of candidates at each stage. In this study, the number of candidates at each stage is varied as a parameter and performances of ES-MLD and S-MLD are evaluated by computer simulations.

2. Proposed Method

In ES-MLD, the signal path search space is expanded by adding interference signal space to the desired signal space. For each spatial signal stream including the interference streams, multiple signal candidates are successively selected using the minimum mean square error (MMSE) equalizer. Subsequently, likelihoods for all combinations of signal candidates are calculated and the signal set with the maximum likelihood is selected as the decoded signal set. In the following, the decoding procedure is briefly explained.

Initially, the access point (AP) transmits orthogonal preambles for multiple MSs to estimate the channel response not only for the desired signals, but also for the undesired signals. Here, the block diagonalization (BD) approach [3], e.g., ZF beamforming, which achieves high channel capacity with a low calculation complexity level, is used for transmit beamforming at the AP. At the MS, the channel responses between multiple transmit beams at the AP and antennas at the MS are estimated from the received preambles. The estimated channel response matrix, $\mathbf{H}^{(1)}$ of size $M \times K$ and the received signal vector, $\mathbf{r}^{(0)}$ of size $M \times 1$ are input into the first stage of the candidate selector. Term K represents the number of spatial signal streams including interference streams and

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M is the number of antenna branches at a MS. Figure 1 shows a block diagram of the *k*-th stage candidate selector.

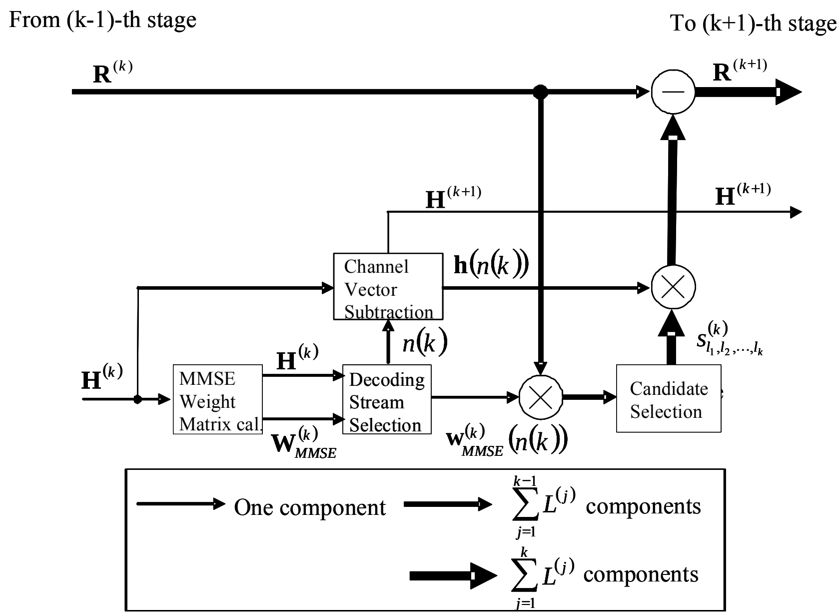

Figure 1: Block diagram of k-th stage candidate selector

The channel response matrix, $\mathbf{H}^{(k)}$ of size $M \times (K-k+1)$ and sets of signal vectors, $\mathbf{R}^{(k)}$ are input from the (*k*-1)-th stage and $\mathbf{R}^{(k)}$ is defined as follows.

$$\mathbf{R}^{(k)} = \left\{ \mathbf{r}^{(k-1)}_{l_1,l_2,\cdots,l_{k-1}} : l_1 = 1,\cdots,L^{(1)},\cdots,l_{k-1} = 1,\cdots,L^{(k-1)} \right\}, \quad (1)$$

$$\mathbf{r}^{(k)}_{l_1,l_2,\cdots,l_k} = \mathbf{r}^{(k-1)}_{l_1,l_2,\cdots,l_{k-1}} - \mathbf{h}^{(n(k))} s^{(k)}_{l_1,\cdots,l_k}, \quad (2)$$

where $L^{(k)}$ is the number of candidates at the *k*-th stage, l_k is the candidate index of the *k*-th stage, and $s^{(k)}_{l_1,\cdots,l_k}$ is determined by the candidate selection block as one of the candidates near hard-decided symbol $\hat{s}^{(k)}$ with respect to the Euclidean distance. The output of the MMSE equalizer is expressed as

$$y^{(k)} = \mathbf{w}^{(k)}_{MMSE}(n(k)) \mathbf{r}^{(k-1)}_{l_1,l_2,\cdots,l_{k-1}}, \quad (3)$$

where $\mathbf{w}^{(k)}_{MMSE}(n(k))$ is the MMSE weight vector at the *k*-th stage. Term $\mathbf{w}^{(k)}_{MMSE}(i)$ is the *i*-th row vector of MMSE weight matrix $\mathbf{W}^{(k)}_{MMSE}$ of the *k*-th stage. Term $\mathbf{W}^{(k)}_{MMSE}$ is calculated from $\mathbf{H}^{(k)}$

$$\mathbf{W}^{(k)}_{MMSE} = (\mathbf{H}^{(k)H} \mathbf{H}^{(k)} + \frac{1}{\rho} \mathbf{I})^{-1} \mathbf{H}^{(k)H}. \quad (4)$$

where ρ is the SNR (Signal to Noise Ratio) per antenna branch. Term $\hat{s}^{(k)}$ is defined as the nearest constellation from the output of the MMSE equalizer. Column vector $\mathbf{h}^{(n(k))}$ denotes the $n(k)$ column of $\mathbf{H}^{(1)}$ and $n(k)$ is determined in the following procedure for the decoding stream selection block. At the decoding stream selection block, the output signal to interference plus noise ratio (SINR) is calculated as

$$SINR_k(i) = \frac{\left\| \mathbf{w}_{MMSE}^{(k)}(i)\mathbf{h}^{(k)}(i) \right\|^2}{\sum_{j=1, i \neq j}^{K-k+1} \left\| \mathbf{w}_{MMSE}^{(k)}(j)\mathbf{h}^{(k)}(j) \right\|^2 + \left\| \mathbf{w}_{MMSE}^{(k)}(i) \right\|^2 \sigma_n^2}, \qquad (5)$$

where $\mathbf{h}^{(k)}(i)$ is the *i*-th column vector of $\mathbf{H}^{(k)}$. The signal stream that has the highest SINR is selected using Eq. (5). Here, the column vector index of $\mathbf{H}^{(1)}$ corresponding to the selected data stream is expressed as $n(k)$. For the next stage, $\mathbf{H}^{(k+1)}$ is generated by extracting the channel response vector $\mathbf{h}^{(n(k))}$ from $\mathbf{H}^{(k)}$, and $\mathbf{R}^{(k)}$ is updated to $\mathbf{R}^{(k+1)}$ using Eq. (1) and (2).

When incremental k reaches the number of all streams, K, the entire candidate set can be expressed as $\left\{ s_{l_1,\cdots,l_k}^{(k)} : \forall l_1,\cdots,l_k, \forall k (1 \le k \le K) \right\}$. Then the metrics of all candidates are calculated. The candidate set corresponding to the minimum metric is selected as the decoded streams.

Since the proposed method estimates the channel responses not only for the desired signals but also for the undesired signals, the search space is expanded. Therefore, the transmission quality is improved when the interference occurs in the time varying channel. The performance of the proposed ES-MLD method is compared to the conventional S-MLD method in the next section.

3. Performance Evaluation

3.1 Simulation model

Transmit beamforming, e.g., ZF beamforming, is generated to suppress interference between users. Thus, the received signal vector of the *j*-th user can be expressed as follows.

$$\mathbf{r}_j = (\mathbf{H}_j + \Delta\mathbf{H}_j)\mathbf{W}_{d,j}\mathbf{s}_d + \Delta\mathbf{H}_j\mathbf{W}_{u,j}\mathbf{s}_u = (\mathbf{A} + \mathbf{B})\mathbf{s}_d + \mathbf{C}\mathbf{s}_u, \qquad (6)$$

Here, $\mathbf{H}_j$ is the channel response matrix of the *j*-th user, $\Delta\mathbf{H}_j$ is the variation part of the channel response matrix, $\mathbf{W}_{d,j}$ is the transmit weight matrix for the *j*-th user, $\mathbf{W}_{u,j}$ is the transmit weight matrix of other users, $\mathbf{s}_d$ is the transmit signal vector of the desired user, and $\mathbf{s}_u$ is the transmit signal vector of an undesired user. It is clear that there is no correlation between matrices $\mathbf{A}$, $\mathbf{B}$ and $\mathbf{C}$ because the variation part of the channel response matrix is independent of the channel response matrix and $\mathbf{W}_{u,j}$ can be considered to be statistically independent from $\mathbf{W}_{d,j}$.

In the following, we consider equal power allocation at the transmitter, i.e., the magnitude of the column vector in each weight matrix, $\mathbf{W}_{d,j}$ and $\mathbf{W}_{u,j}$, are equal to each other. Thus, the variance of an entity of $\mathbf{B}$ is equal to that of $\mathbf{C}$ where the variance indicates the magnitude of the variation part of the channel response matrix.

3.2 Simulation results

The performance of ES-MLD is compared to that of S-MLD based on computer simulations using the model described in the previous section. The variance of each entity of $\mathbf{A}$ is set to one and those of $\mathbf{B}$ and $\mathbf{C}$ are set to the variance of the estimation error, which is related to the Doppler frequency and the time gap of the CSI measurement at the AP and MS. In the simulation, the number of users is set to two. The number of streams for the desired signals and reception antenna branches is assumed to be two. The SNR per antenna branch is assumed to be 35 dB. The modulation is 16QAM. Figure 2 (a) shows the average BER (Bit Error Rate) for the inverse of the variance of the estimation error when $(L^{(1)} \;\; L^{(2)} \;\; L^{(3)} \;\; L^{(4)}) = (1 \;\; 1 \;\; 1 \;\; 1)$ for ES-MLD, $(L^{(1)} \;\; L^{(2)}) = (1 \;\; 1)$ for S-MLD, respectively. And figure 2 (b) shows the averaged BER when $(L^{(1)} \;\; L^{(2)} \;\; L^{(3)} \;\; L^{(4)}) = (9 \;\; 9 \;\; 9 \;\; 1)$ for ES-MLD, $(L^{(1)} \;\; L^{(2)}) = (9 \;\; 1)$ for S-MLD, respectively. Note that S-MLD has only two entities while ES-MLD has four. This is because ES-MLD detects both the desired and undesired signals. As shown in Fig. 2, the signal path search space is expanded to the undesired signal space, but the performance improvement is little. On the other hand, Fig. 2 (b) shows that the variance of the estimation error to attain the BER of 10^{-2} of ES-MLD is about 10dB larger than that of S-MLD. These results indicate that the proposed ES-MLD can improve the transmission quality by increasing the number of candidates at each stage while the further improvement is not expected in S-MLD.

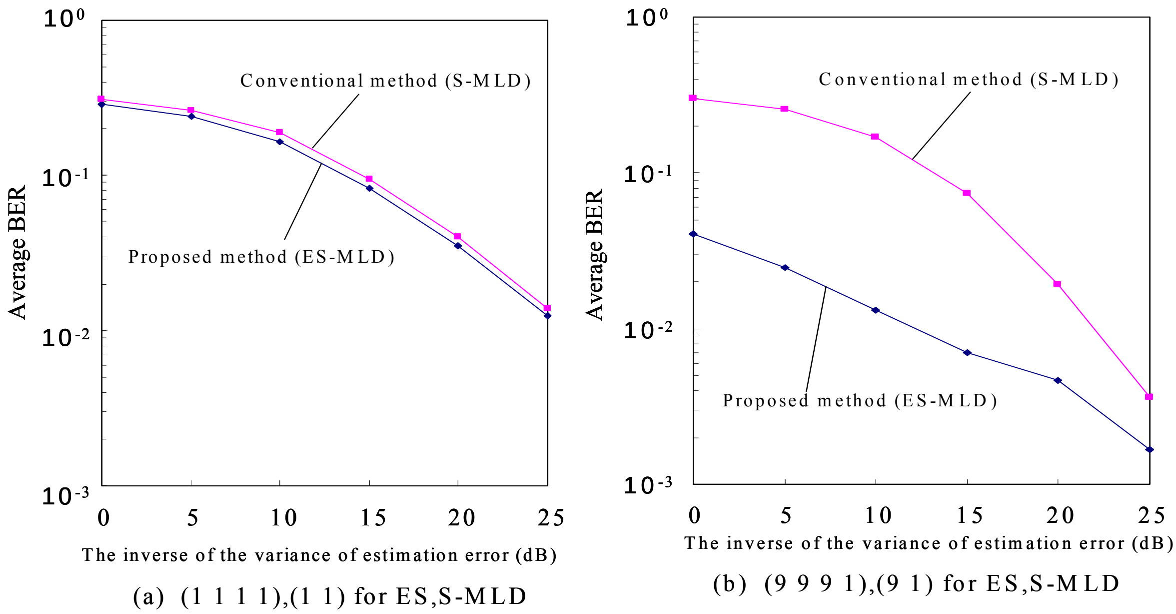

Figure 2: Average BER performance

4. Conclusion

This paper proposed enhanced simplified maximum likelihood detection (ES-MLD) method for the multiuser MIMO downlink in a time-variant environment. In the proposed method, the signal search space includes not only the desired signal space but also interference signal space. The average BERs for the variance of the estimation error are evaluated by computer simulations. The simulation results confirm that the proposed method is robust against the changes in the environment. Moreover, it is found that the proposed ES-MLD can achieve the further improvement by increasing the number of candidates while the conventional S-MLD slightly improves the performance with large number of candidates.

Acknowledgments

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