

Enhanced Simplified Maximum Likelihood Detection (ES-MLD) in multi-user MIMO downlink in time-variant environment

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Abstract

Support for a large number of users is required for the next generation wireless access systems and very high channel capacity must be achieved. The Multiuser-MIMO (MU-MIMO) technique has attracted much attention because of its high spectrum efficiency. However, in downlink MU-MIMO, channel state information (CSI) estimation error occurs in a time varying environment and the transmission quality is degraded. In this paper, we propose a new transmission and decoding method based on simplified maximum likelihood detection (S-MLD), which was proposed for single user MIMO systems. Since the dimensions of the signal path search space are expanded by adding interference signal space to the desired signal space, the proposed method is robust against the interference caused by the channel variation in MU-MIMO. The effectiveness of the proposed method is confirmed by computer simulation.

Key words: *multiuser MIMO, downlink, MLD, simplified MLD, time-variant environment*

1. INTRODUCTION

In the next generation wireless access systems, a very high channel capacity must be achieved to support a large number of high data rate users. Due to limited frequency resources, multiple input multiple output (MIMO) techniques have attracted attention as an efficient spatial resource utilization technique to improve the spectrum efficiency [1]. Since MIMO techniques increase the channel capacity proportionally to the number of antenna branches at both ends, the application of MIMO techniques to various wireless access systems, e.g., cellular systems / wireless local area networks (W-LANs), has been studied [2] [3]. However, for simple mobile stations (MSs), the number of available antenna branches is small so a large MIMO effect cannot be expected. To

overcome this problem, the multiuser MIMO (MU-MIMO) technique was proposed [4]. In MU-MIMO systems, an access point (AP) accesses multiple MSs simultaneously using the same frequency channel by utilizing all available spatial resources, and a very high channel capacity can be achieved even for simple MSs.

In downlink MU-MIMO systems, two transmission approaches were proposed to accommodate multiple users, non-linear pre-coding [5] and transmit beamforming [6]. Although non-linear pre-coding such as dirty paper coding (DPC) is known to achieve an ideal channel capacity, a practical coding method has not been developed. Thus, in the following, we will focus on the transmit beamforming approach.

Zero-forcing (ZF) beamforming method was proposed for the downlink MU-MIMO to suppress inter-user-interference (IUI) [6]. With ZF transmit beamforming, only desired signals are received at each MS and any decoding algorithm for single user MIMO (SU-MIMO) can be used. Thus, the calculation complexity at each MS does not increase while ZF transmit beamforming requires accurate channel state information (CSI) to control the null space [6]. In the presence of CSI estimation error, IUI occurs and the number of signal streams may exceed the number of antenna branches at the MS. Thus, no linear decoding algorithm can eliminate the interference. In a time varying environment, CSI estimation error is unavoidable even when using the extrapolation approach [7]. Therefore, a new decoding algorithm that is robust against IUI is required to apply the MU-MIMO technique in a time varying environment.

Although maximum likelihood detection (MLD) is the best decoding method for SU-MIMO, the calculation complexity level is prohibitively high. To reduce the calculation complexity level, simplified MLD (S-MLD) was proposed [8]. In S

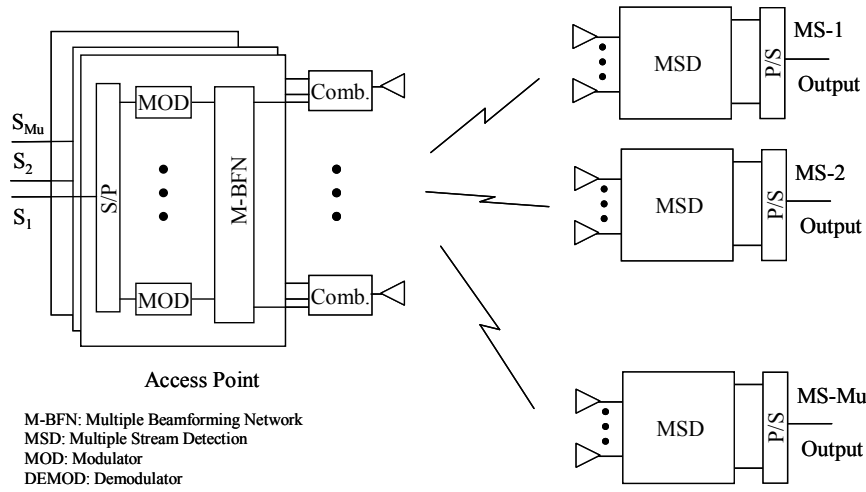


Figure 1. Downlink MU-MIMO system

-MLD, the number of candidates for the desired signal sets is decreased through a successive detection approach and the calculation complexity level is sufficiently lowered for actual hardware implementation while the performance level comparable to that of ideal MLD is maintained. However, the performance of S-MLD is vulnerable to unexpected interference, and the improvement in transmission quality is insufficient 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 method, enhanced S-MLD (ES-MLD), the dimensions of the signal path search space are expanded by adding the interference signal space to the desired signal space. ES-MLD improves the transmission quality with an appropriate increase in the calculation cost. In ES-MLD, the orthogonal preambles for all users are transmitted. Thus, the MS can estimate the channel responses for not only the desired signals but also the undesired signals. The performance of ES-MLD is shown by computer simulation.

In the following, Section 2 describes the proposed method and Section 3 presents computer simulation results to confirm the effectiveness of the proposed method. Finally, Section 4 summarizes this paper.

2. PROPOSED METHOD

Figure 1 shows the configuration of the typical MU-MIMO system. The AP has M_T antenna branches and the MS has M antenna branches. AP transmits the signals to multiple MSs simultaneously with multiple beams. At MSs, the signals are decoded by the multiple signal detector where the conventional S-MLD or the proposed ES-MLD is employed.

In ES-MLD, the signal path search space is expanded by adding an interference signal space to the desired signal space. For each spatial signal stream including the interference streams, multiple signal candidates are selected using the minimum mean square error (MMSE) equalizer successively. 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 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 [6], e.g. ZF beamforming, which achieves high channel capacity with low calculation complexity, is used for transmit beamforming at the AP. At the MS, the channel

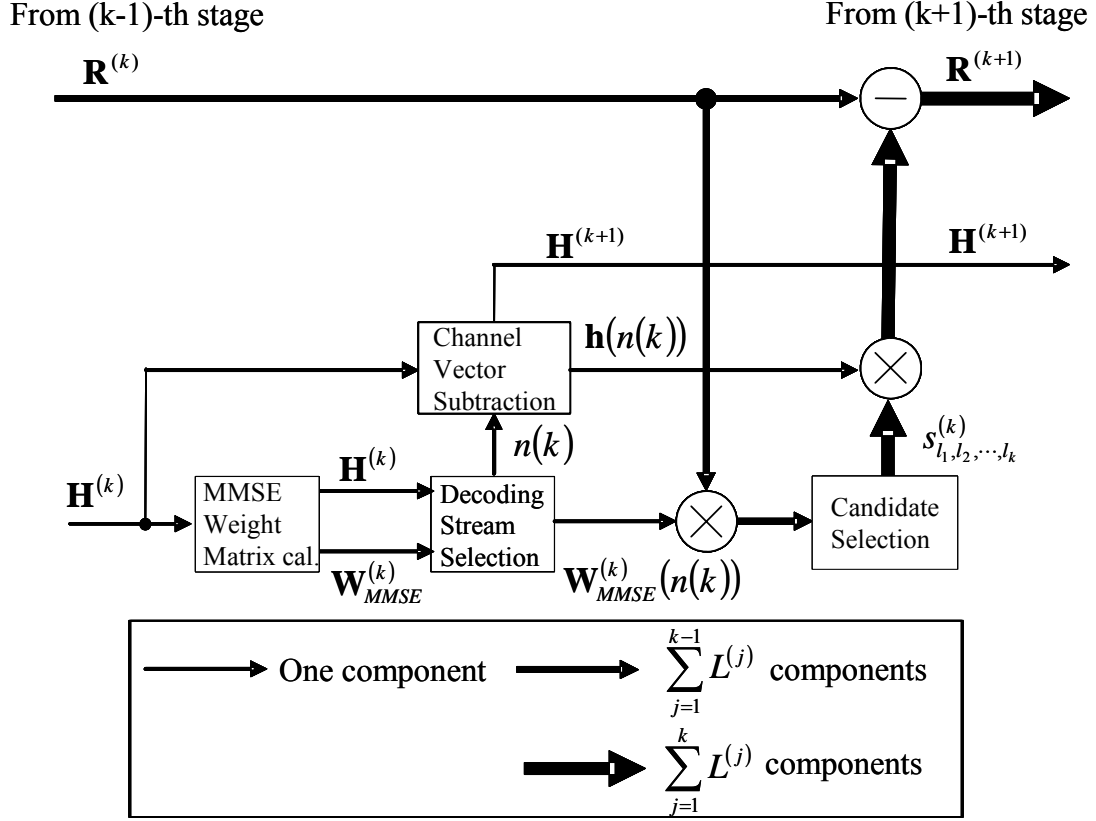


Figure 2. Block diagram of k -th stage candidate selector

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 to the first stage of the candidate selector. Term K represents the number of spatial signal streams including interference streams and M is the number of antenna branches at a MS.

Figure 2 shows a block diagram of the 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.

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

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

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 $s_{l_1, \dots, l_k}^{(k)}$ is determined by the candidate selection block as one of the candidates near hard-decided symbol $\hat{s}^{(k)}$ with respect to Euclidean distance. Output of the MMSE equalizer is expressed as

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

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

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

where ρ is the SNR per antenna branch. $\hat{s}^{(k)}$ is defined as the nearest constellation from the

output of MMSE equalizer. Column vector $\mathbf{h}^{(n(k))}$ denotes the $n(k)$'s 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

$$\begin{aligned} \text{SINR}_k(i) &= \frac{\|\mathbf{w}_{MMSE}^{(k)}(i)\mathbf{h}^{(k)}(i)\|^2}{\sum_{j=1, i \neq j}^{K-k+1} \|\mathbf{w}_{MMSE}^{(k)}(j)\mathbf{h}^{(k)}(j)\|^2 + \|\mathbf{w}_{MMSE}^{(k)}(i)\|^2 \sigma_n^2}, \end{aligned} \quad (5)$$

where $\mathbf{h}^{(k)}(i)$ is the i -th column vector of $\mathbf{H}^{(k)}$. The signal stream which has the highest SINR is selected by using Eq. (5). Here, the column vector index of $\mathbf{H}^{(1)}$ corresponding to the selected data stream is expressed by $n(k)$.

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 Eq.(2).

When the incremental k reaches to the number of all streams, K , the whole candidate set can be expressed as

$$\{s_{l_1, \dots, l_k}^{(k)} : \forall l_1, \dots, l_k, \forall k(1 \leq k \leq K)\}.$$

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 method, ES-MLD, is compared with the conventional S-MLD method in the next section.

3. PERFORMANCE EVALUATION

The proposed method is evaluated by computer simulation. At first, the zero-forcing transmit beam-forming method is explained and the simulation model is derived. Then, based on the model, the proposed method is evaluated based on a parameter study.

Various antenna configurations and the number of transmit streams are the parameters. In the simulation, the number of users is fixed at two.

3.1 Simulation model

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

$$\begin{aligned} \mathbf{r}_j &= (\mathbf{H}_j + \Delta\mathbf{H}_j)\mathbf{W}_{d,j}\mathbf{s}_d + \Delta\mathbf{H}_j\mathbf{s}_u, \\ &= (\mathbf{A} + \mathbf{B})\mathbf{s}_d + \mathbf{C}\mathbf{s}_u \end{aligned} \quad (6)$$

Here, \mathbf{H}_j is the channel matrix of the j -th user, $\Delta\mathbf{H}_j$ is the variation part of the channel 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, \mathbf{s}_u is the transmit signal vector of an undesired user, $\mathbf{A} = \mathbf{H}_j\mathbf{W}_{d,j}$, $\mathbf{B} = \Delta\mathbf{H}_j\mathbf{W}_{d,j}$, and $\mathbf{C} = \Delta\mathbf{H}_j\mathbf{W}_{u,j}$.

It is clear that there is no correlation between \mathbf{A} and \mathbf{B} because the variant of the channel matrix, $\Delta\mathbf{H}_j$, is independent of \mathbf{H}_j . Thus, the correlation between \mathbf{A} and \mathbf{C} is also independent. Since $\mathbf{W}_{d,j}$ is determined based on the channel matrix of the undesired users and $\mathbf{W}_{u,j}$ is constrained to be orthogonal to the desired channel matrix, $\mathbf{W}_{d,j}$ and $\mathbf{W}_{u,j}$ are statistically independent. Therefore, we assume no correlation among channel matrices \mathbf{A} , \mathbf{B} , and \mathbf{C} .

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 $\mathbf{W}_{u,j}$, is 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 channel variation.

3.2 Simulation result

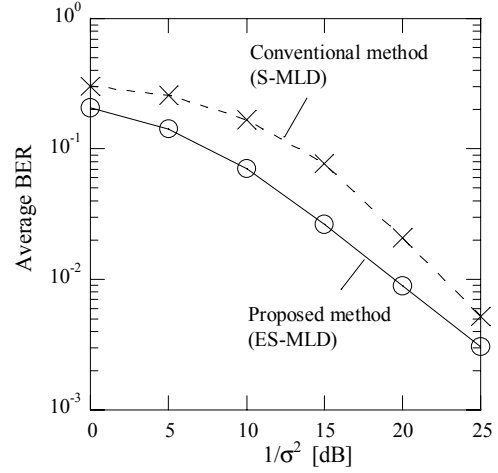
The performance of ES-MLD is compared to that of S-MLD based on computer simulations using the model described in the previous section. The variance of each entity of \mathbf{A} is set to one and that of \mathbf{B} and \mathbf{C} is set to σ^2 . In the simulation, the number of users is fixed at two. The number of streams for desired signals is assumed to be equal to or less than the number of reception

antenna branches. The SNR per antenna branch is assumed to be 35dB. The number of receive antennas is varied from two to four. The modulation is 16QAM.

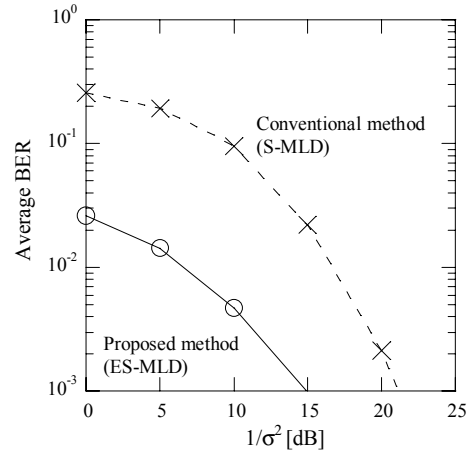
Figure 3 show the Average BER for the variance of the matrix \mathbf{B} or \mathbf{C} , σ^2 . The number of reception antenna branches is two or three, the number of streams is two, and the number of candidates at each stage are set to [5 1 1 1] and [5 1] for ES-MLD, S-MLD respectively. Here, the k -th element of $[l_1 l_2 \dots l_K]$ represents the number of candidates at the k -th stage. 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. It is found that the proposed ES-MLD outperforms S-MLD regardless of the number of receive antenna branches. Thus, Fig. 3(a) and Fig. 3(b) confirm that ES-MLD is robust for the environment changes compared to S-MLD. When the number of reception antenna is two, the variance of the matrix \mathbf{B} or \mathbf{C} to attain the BER of 10^{-2} of ES-MLD is 3.2 dB larger than that of S-MLD.

Figure 4 represents the influence of the number of signal streams. The number of reception antenna branches is four. The number of candidates in the first stage is set to five and those in other stages are set to one for both S-MLD and ES-MLD. The figure shows that the advantage of the proposed method increases as the number of signal streams decreases. When the number of streams is small, interference is sufficiently suppressed, and the difference of performance between ES-MLD and S-MLD is small.

Figure 5 shows the influence of number of candidates, which is directly related to the calculation complexity. The number of reception antenna branches is four, the number of desired signal streams is four and the number of undesired signal streams is four. In this evaluation, the numbers of candidates at the first x stages are set to five while those at the other stages are assumed to be one. In case that x is set to 2 for ES-MLD, the number of candidates for the first and the second stages is five and that of third to eighth stages is one. In fig. 5, the horizontal axis represents x so the calculation complexity increases as the horizontal axis increases. Fig. 5 shows that the advantage of the proposed method increases as the calculation complexity decreases.



(a) $M=2, K=4, SNR=35dB$



(b) $M=3, K=4, SNR=35dB$

Figure 3. Average BER performances.

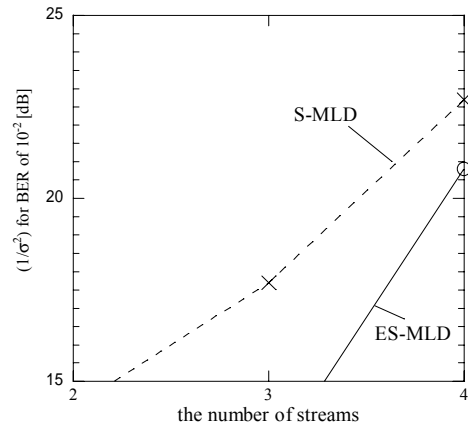


Figure 4. Influence of the number of desired signal streams.

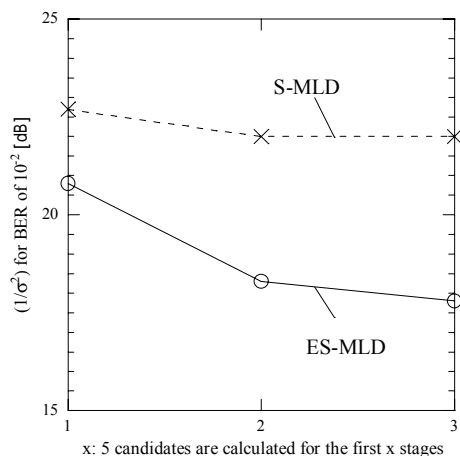


Figure 5. Influence of the number of candidates on the environment changes.

And compared with lowest complex S-MLD and next more complex ES-MLD, the difference of required SIR is about 4dB. Even when the complexity is same, the difference is 1.8dB.

4. CONCLUSION

This paper proposed enhanced simplified maximum likelihood detection (ES-MLD) in the multi-user MIMO downlink in a time-variant environment. In the proposed method, the signal search space includes not only desired signal space but also interference signal space. The average BER and the required time variance of the channel matrix for the BER of 10^{-2} are evaluated by computer simulation. The simulation results confirm that the proposed method is robust for the environment changes regardless of the number of signal streams and the number of candidates.

Acknowledgement

This work is supported by the Ministry of Internal Affairs and Communications, Japan, under the grant, "Research and development of fundamental technologies for advanced radio frequency spectrum sharing in mobile communication systems."

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