Uplink Multi-User MIMO Detection via Parallel Access

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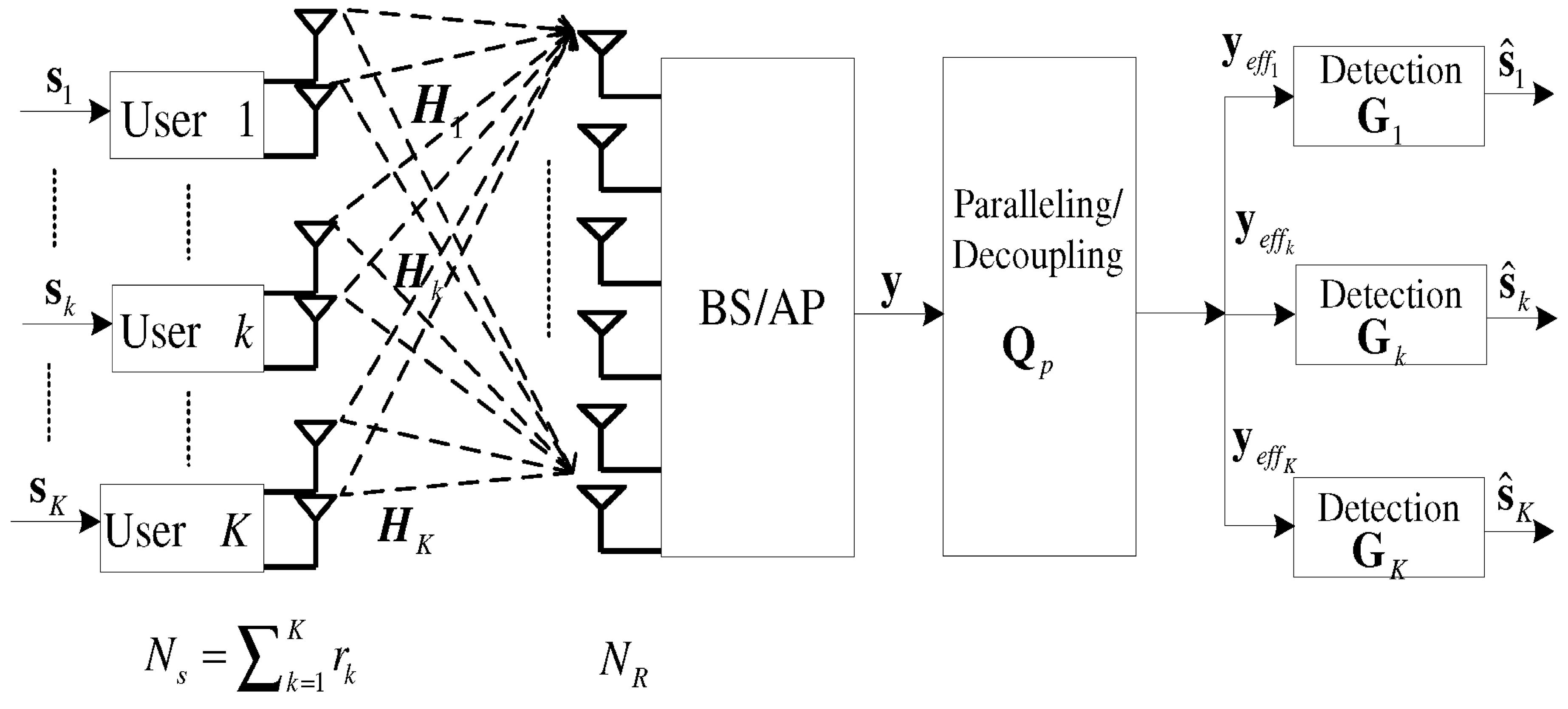
Motivation and Problem Statement

- A limiting factor for capacity of a radio network is the amount of available radio resources.
- The application of UL MU-MIMO can considerably improve the utilization of radio resources.
- The conventional UL MU-MIMO detection algorithms cannot scale up with the system dimensions both in terms of performance and delay.
- The conventional UL MU-MIMO detection algorithms cannot be customized to individual requirements (i.e., channel quality, QoS, etc.) for scheduled users in the same RF blocks.
- In this work, two parallelizing access methods for UL MU-MIMO systems are developed. The multi-user interference is completely removed or efficiently suppressed by the proposed parallelizing process.

Proposed Parallel Access Methods for UL MU-MIMO

- As depicted in Fig. 1, the signals from multiple users can be separated from each other and individual users can be detected in parallel as if the other users did not exist.



$\mathbf{s}_k$	transmitted k-th user's data signal	$\mathbf{Q}_p$	combined paralleling matrix
$\mathbf{H}_k$	k-th user's channel matrix	$\mathbf{y}_{eff_k}$	the effective received k-th signal
$\mathbf{n}$	AWGN noise	$\hat{\mathbf{s}}_k$	estimated k-th user's data signal
$\mathbf{y}$	received signal	$\mathbf{G}_k$	k-th user's detection matrix

Fig.1 The system structure of the proposed UL MU-MIMO parallel access scheme

Derivation of the Parallel Access Techniques

ZF Decoupling

We calculate the pseudo-inverse of the combined channel matrix $\boldsymbol{H}$ as

$$\boldsymbol{H}^{+} = (\boldsymbol{H}^H \boldsymbol{H})^{-1}\boldsymbol{H}^H = \begin{bmatrix} \boldsymbol{H}_1^{+} \\ \vdots \\ \boldsymbol{H}_k^{+} \\ \vdots \\ \boldsymbol{H}_K^{+} \end{bmatrix}, \qquad (12)$$

where the quantity $\boldsymbol{H}_k^{+}$ is the k-th sub-matrix of $\boldsymbol{H}^{+}$. Given that $\boldsymbol{H}^{+}\boldsymbol{H} = \boldsymbol{I}_{N_S}$, we have,

$$\boldsymbol{H}_k^{+}\boldsymbol{H}_k = \boldsymbol{I}_{r_k},\ \boldsymbol{H}_k^{+}\boldsymbol{H}_j = \boldsymbol{0}\ \forall j \neq k. \qquad (13)$$

Next, we perform the LQ decomposition of $\boldsymbol{H}_k^{+}$ as

$$\boldsymbol{H}_k^{+} = \boldsymbol{L}_k \boldsymbol{Q}_k, \qquad (14)$$

where the quantity $\boldsymbol{L}_k \in \mathbb{C}^{r_k \times r_k}$ is a lower triangular matrix and $\boldsymbol{Q}_k \in \mathbb{C}^{r_k \times N_R}$ has unitary rows. Substituting (14) into (13), since $\boldsymbol{L}_k$ is invertible, we have

$$\boldsymbol{Q}_k \boldsymbol{H}_j = \boldsymbol{0}\ \forall j \neq k. \qquad (15)$$

MMSE Decoupling

The regularized inversion of the combined channel matrix

$$\boldsymbol{H}_{\text{mmse}}^{+} = (\boldsymbol{H}^H \boldsymbol{H} + \alpha \boldsymbol{I}_{N_s})^{-1}\boldsymbol{H}^H = \begin{bmatrix} \boldsymbol{H}_{(\text{mmse},1)}^{+} \\ \vdots \\ \boldsymbol{H}_{(\text{mmse},k)}^{+} \\ \vdots \\ \boldsymbol{H}_{(\text{mmse},K)}^{+} \end{bmatrix}, \qquad (19)$$

where the parameter α is the regularization factor and the quantity $\boldsymbol{H}_{(\text{mmse},k)}^{+} \in \mathbb{C}^{r_k \times N_R}$ is the k-th sub-matrix of $\boldsymbol{H}_{\text{mmse}}^{+}$. Similar to the ZF decoupling, we have the following relationship

$$\boldsymbol{H}_{(\text{mmse},k)}^{+}\boldsymbol{H}_k \approx \boldsymbol{I}_{r_k},\ \boldsymbol{H}_{(\text{mmse},k)}^{+}\boldsymbol{H}_j \approx \boldsymbol{0}\ \forall j \neq k, \qquad (20)$$

We perform the LQ decomposition of $\boldsymbol{H}_{(\text{mmse},k)}^{+}$ as

$$\boldsymbol{H}_{(\text{mmse},k)}^{+} = \boldsymbol{L}_{(\text{mmse},k)}\boldsymbol{Q}_{(\text{mmse},k)}, \qquad (21)$$

where the quantity $\boldsymbol{L}_{(\text{mmse},k)} \in \mathbb{C}^{r_k \times r_k}$ is a lower triangular matrix and $\boldsymbol{Q}_{(\text{mmse},k)} \in \mathbb{C}^{r_k \times N_R}$ has unitary rows. Since $\boldsymbol{L}_{(\text{mmse},k)}$ is invertible, we have

$$\boldsymbol{Q}_{(\text{mmse},k)}\boldsymbol{H}_j = \boldsymbol{0}\ \forall j \neq k. \qquad (22)$$

Simulation Results

- As shown in Fig. 2, the system dimensions are increased to involve up to 60 receiving antennas and 15 users, each user transmitting 4 data streams.
- The proposed MD-P-MMSE can achieve 5.2 dB and 1.5 dB gains over the conventional MMSE and MMSE-SIC at a BER of 10^{-3}, respectively.
- The proposed MD-P-MMSE can scale up with the system dimensions both in terms of performance and delay.

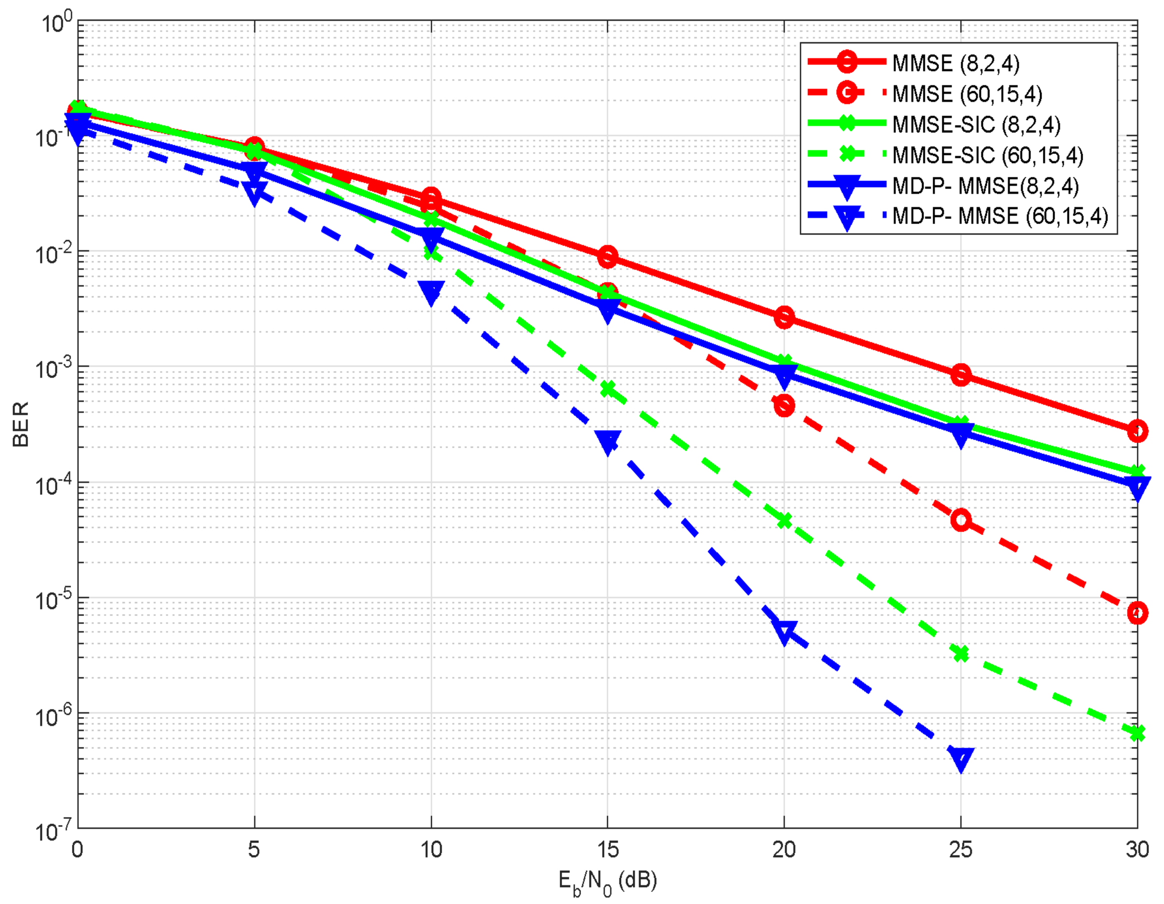


Fig.2 Comparision of the proposed *MMSE decoupling parallel MMSE* (MD-P-MMSE) with MMSE and MMSE-SIC.

- For the system configuration (400, 200, 2) shown in Fig. 3, we apply matched filtering (MF) detection to each individual user after the proposed MMSE decoupling process.
- The BER performance of the proposed MMSE decoupling with parallel MF (MD-P-MF) is even better than that of the MMSE-SIC in the medium-low SNR region with less delay.
- As shown by Fig. 4, the increased complexity is reasonable with low to medium system dimensions, which makes the proposed methods very attractive solutions.

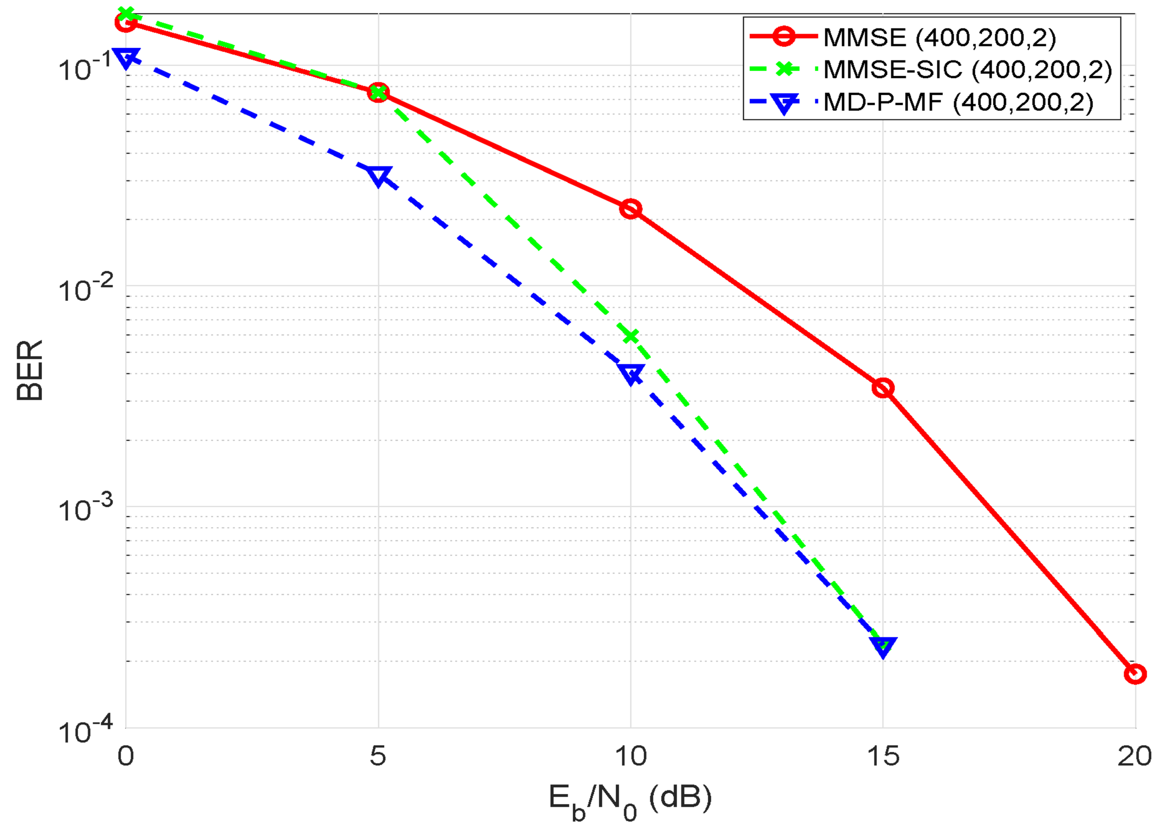


Fig. 3 Comparision of the proposed MMSE decoupling parallel MF (MD-P-MF) with conventional MMSE and MMSE-SIC for the system configuration (400, 200, 2).

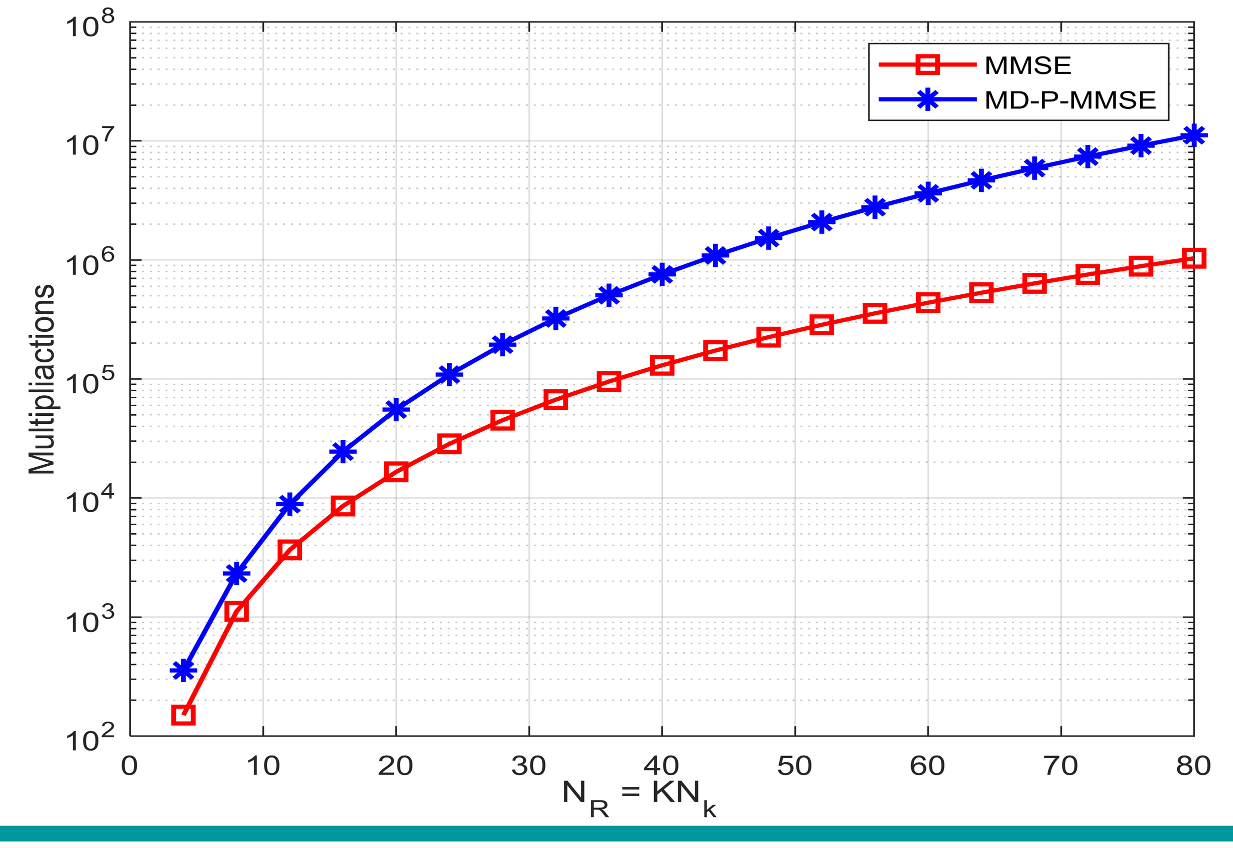


Fig. 4 Comparision of the computational complexity with assumption $N_S=N_R=KN_k$.

Contributions

- The utilization of radio resources can be improved by allowing multiple UL users to access the same radio resource simultaneously.
  - ⇒ Thus, the throughput of a radio network can be improved.
- The proposed parallel access methods provide extra flexibility to UL MU-MIMO detection.
  - ⇒ The received signals from multiple uplink users are decoupled.
  - ⇒ Therefore, a customized detection strategy can be implemented per user.
- The proposed detection methods can scale up with the system dimensions both in terms of the bit error rate (BER) and the detection delay.