Efficient SVD-based Transmission Strategy against High-Speed Mobility in TDD MIMO Systems

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***Abstract*—The performance of a system, which uses singular value decomposition (SVD) over a multiple-input multiple-output (MIMO) channel, depends on the accuracy of the channel state information (CSI) at the transmitter and the receiver. And although, SVD-based transmission can be done without any feedback by utilizing the channel reciprocity in time-division duplex (TDD) systems, the CSI at the transmitter is always outdated in time-varying channels, especially in the high-speed mobility cases. As in such cases, a typical system employing conventional SVD-based transmission will suffer great degradation in both capacity and BER performance, due to the interference among the sub-channels. So, a more efficient SVD-based transmission strategy against high-speed mobility is proposed in this paper. Compared with other transmission schemes, the novel transmission scheme can achieve significant performance improvement with lower computation complexity. And the simulation results do indicate that the proposed scheme is more robust against the outdated CSI. Besides, the analysis of both signal to interference-plus-noise ratio (SINR) and computation complexity are provided.**

***Index Terms*—MIMO systems, TDD, SVD, Mobility**

I. Introduction

Multiple-input and multiple-output (MIMO) technique is being widely used in the next generation communication systems such as the Long Term Evolution (LTE) systems and WiMax systems, due to the advantages of improving the spectral efficiency without increasing the bandwidth and transmit power [1]. The SVD-based MIMO systems can approach the theoretical MIMO channel capacity when perfect channel state information (CSI) is available at both the transmitter and the receiver. The MIMO channels can be decoupled into parallel eigen-subchannels by means of SVD, which enables the data transmissions in independent sub-channels without any interference. But the independent sub-channels can only be obtained when perfect CSI is available.

In practical systems, such as TDD systems, perfect CSI is rarely available at the transmitter. As both uplink and downlink share the same frequency bands, channel reciprocity is utilized to gain the downlink CSI by estimating the uplink CSI. Thus, for the time-varying channel, the channel information used at the transmitter is imperfect because of estimation errors and delay. And the precoding matrix processing at the transmitter does not match with the actual channel. The mismatch causes interferences among the sub-channels and leads to significant performance loss, especially in high-speed mobility circumstances due to the rapid channel variation. Thus it's crucial to investigate the capacity and BER performance of SVD-based MIMO systems under high-speed mobility.

The average signal-to-noise ratio (SNR) approximation [2] has been introduced to discuss the performance degradation caused by the CSI error. Further, linear receivers, such as ZF and MMSE, for SVD-based MIMO systems under time-varying channels have been investigated. The simulation results indicate that the interference caused by imperfect CSI significantly degrades the capacity performance, especially when the variation is dramatic [3]. And Pandula has focused on the SINR and MSE. Performance of capacity and MSE in the research shows that SVD-based precoding suffers severe deterioration as correlation decreases in high-speed mobility cases [4]. Hence, a more efficient transmission strategy against user's high-speed mobility is desired.

In this paper, we propose a novel transmission strategy in the SVD-based TDD MIMO systems. It is a low complexity scheme which can achieve significant performance gains over high mobility. First, the transmitter exploits a linear spatial precoding at the pilot stage to obtain the equivalent channel matrix; and at the receiver, the equivalent matrix is decomposed with the triangular matrix's diagonal entries sorted. Then, successive interference cancelation (SIC) is utilized to suppress the sub-channel interference. Because of the appropriate detection order produced by the precoding, the sorting process and sub-channel interference cancelation operation, the proposed transmission strategy is more efficient against user's high-speed mobility than the existing schemes.

II. System Model

A. Time-Varying Channel Model

We consider a flat fading MIMO channel with N_t transmit antennas and N_r receive antennas ($N_r \geq N_t$). The time-varying channel at time t is represented by $N_r \times N_t$ matrix $\boldsymbol{H}_t$. The entries of $\boldsymbol{H}_t$ are assumed to be independent identically distributed (i.i.d) and $H_{ij} \sim \mathcal{CN}(0,1)(1 \leq i \leq N_r, 1 \leq j \leq N_t)$. To characterize the outdated CSI, the channel time variation is described by the first-order Markov process[5]

$$\boldsymbol{H}_t = \rho \boldsymbol{H}_{t-\tau} + \mathcal{K}\boldsymbol{\Xi}_t \tag{1}$$

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where τ denotes the delay, the outdated channel $\boldsymbol{H}_{t-\tau}$ is known at the transmitter instead of the true channel $\boldsymbol{H}_t$, ρ stands for the time correlation coefficient and $\mathcal{K} \triangleq \sqrt{1-\rho^2}$. The term $\boldsymbol{\Xi}$ also has i.i.d entries and $\Xi_{ij} \sim \mathcal{CN}(0,1)$. And the temporal correlation ρ is defined as $\rho = \mathbb{E}[\boldsymbol{H}_t \boldsymbol{H}_{t-\tau}^H]$. In Jake's model for simplicity $\rho(f_d\tau) = J_0(2\pi f_d \tau)$ [6], where $J_0(\cdot)$ is the zero-*th* order Bessel function of the first kind and f_d denotes the Maximum Doppler Frequency shift.

B. SVD-based MIMO Processing in TDD Systems

Considering a point to point MIMO system with N_t transmit and N_r receive antennas, here we assume $N_r = N_t$ for simplicity, the system model of SVD-based MIMO processing in TDD systems is shown in Fig.1.

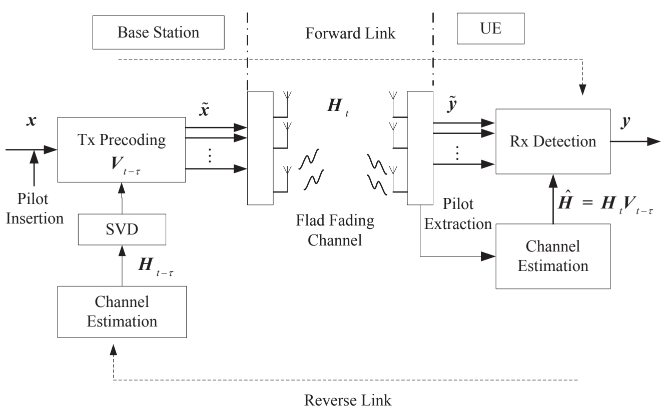

Fig. 1. SVD-based MIMO processing in TDD systems

Over the high-speed mobility environment, the CSI at the transmitter is obviously outdated. Considering the time-varying nature of the channel, the overall transmission process for the conventional SVD based transmission could be written as

$$\boldsymbol{y} = \boldsymbol{U}_t^H \left(\boldsymbol{H}_t \boldsymbol{V}_{t-\tau} \boldsymbol{x} + \boldsymbol{n}\right) \tag{2}$$

where $\boldsymbol{H}_t \in \mathbb{C}^{N_r \times N_t}$ is the channel matrix of time t, $\boldsymbol{x} \in \mathbb{C}^{N_t \times 1}$ is the transmitted vector, $\boldsymbol{y} \in \mathbb{C}^{N_r \times 1}$ is the received data after MIMO decoding. $\boldsymbol{n} \in \mathbb{C}^{N_r \times 1}$ is an additive white Gaussian noise, with zero mean and equal variance in the independent real and imaginary components. $\boldsymbol{V}_{t-\tau} \in \mathbb{C}^{N_t \times N_t}$ is the precoding matrix, $\boldsymbol{U}_t \in \mathbb{C}^{N_r \times N_r}$ is the receiver decoding matrix. And $[\boldsymbol{U}_{t-\tau}, \boldsymbol{\Sigma}_{t-\tau}, \boldsymbol{V}_{t-\tau}] = SVD(\boldsymbol{H}_{t-\tau}), [\boldsymbol{U}_t, \boldsymbol{\Sigma}_t, \boldsymbol{V}_t] = SVD(\boldsymbol{H}_t)$. The SVD of $\boldsymbol{H}$ can be written as $\boldsymbol{H} = \boldsymbol{U}\boldsymbol{\Sigma}\boldsymbol{V}^H$. Here we also assume that $\mathbb{E}(\boldsymbol{n}\boldsymbol{n}^H) = \sigma_n^2 \boldsymbol{I}_{N_r}$, $\mathbb{E}(\boldsymbol{x}\boldsymbol{n}^H) = 0$, $\mathbb{E}(\boldsymbol{x}\boldsymbol{x}^H) = \sigma_x^2 \boldsymbol{I}_{N_t}$.

Eq.(2) can be rewritten as

$$\begin{aligned} \boldsymbol{y} &= \boldsymbol{U}_t^H \boldsymbol{U}_t \boldsymbol{\Sigma}_t \boldsymbol{V}_t^H \boldsymbol{V}_{t-\tau} \boldsymbol{x} + \boldsymbol{U}_t^H \boldsymbol{n} \\ &= \boldsymbol{\Sigma}_t \boldsymbol{\Omega} \boldsymbol{x} + \tilde{\boldsymbol{n}} \\ &= \boldsymbol{\Sigma}_t \boldsymbol{\Omega}_{diag} \boldsymbol{x} + \boldsymbol{\Sigma}_t \boldsymbol{\Omega}_{offd} \boldsymbol{x} + \tilde{\boldsymbol{n}} \end{aligned} \tag{3}$$

where $\tilde{\boldsymbol{n}} = \boldsymbol{U}_t^H \boldsymbol{n}$ is AWGN with $\mathbb{E}(\tilde{\boldsymbol{n}}\tilde{\boldsymbol{n}}^H) = \sigma_n^2 \boldsymbol{I}_{N_r}$, and $\boldsymbol{\Omega} = \boldsymbol{V}_t^H \boldsymbol{V}_{t-\tau} = \boldsymbol{\Omega}_{diag} + \boldsymbol{\Omega}_{offd}, \boldsymbol{\Omega}_{diag} = \boldsymbol{diag}(\boldsymbol{\Omega})$. $\boldsymbol{\Sigma}_t \boldsymbol{\Omega}_{offd} \boldsymbol{x}$ indicates the sub-channel interference caused by the channel variety. Note that $\boldsymbol{\Omega}$ is a unitary matrix whose statistics depends on the correlation $\boldsymbol{\rho}$ between $\boldsymbol{H}_{t-\tau}$ and $\boldsymbol{H}_t$. When the channel is constant over time, which means $\rho = 1, \boldsymbol{H}_{t-\tau} = \boldsymbol{H}_t$. And then $\boldsymbol{\Omega} = \boldsymbol{\Omega}_{diag} = \boldsymbol{I}_{N_r}, \boldsymbol{\Omega}_{offd} = \boldsymbol{0}$. There is no sub-channel interference for ideal SVD transmission. But if the channel is time-varying, especially for the high mobility channels, the CSI at the transmitter and the true channel is rarely correlated. So $\boldsymbol{\Omega}_{offd} \neq \boldsymbol{0}$ and $\Omega_{i,j}$ denotes the interference in i-th sub-channels resulted from j-th subchannel. The capacity and BER will suffer severe performance loss because of the sub-channel interference.

To alleviate the effect of incorrect CSI at the transmitter, [3] proposed a linear processing architecture to mitigate the channel impairment through processing of the received signals. They are referred to as 'SVD+ZF' and 'SVD+MMSE' system in the remainder of the paper.

At the receiver, the equivalent channel after precoding is denoted as $\boldsymbol{H}_{eq} = \boldsymbol{H}_t \boldsymbol{V}_{t-\tau}$, which is obtained through channel estimation. Here we suppose channel estimation is ideal. Since $\boldsymbol{H}_{eq}$ is known at the receiver, linear processing can be applied with the processing matrix $\boldsymbol{G}$.

1) SVD+ZF: For Zero Forcing criterion, the decorrelator receiver simply inverts the effective channel by setting

$$\boldsymbol{G}_{decorr} = \boldsymbol{H}_{\boldsymbol{eq}}^{\dagger} = (\boldsymbol{H}_t \boldsymbol{V}_{t-\tau})^{\dagger} \tag{4}$$

where $(\boldsymbol{.})^{\dagger}$ denotes Moore-Penrose inverse. The decorrelator receiver completely eliminates the interference but leads to noise enhancement.

2) SVD+MMSE: MMSE receiver aims to minimize the mean square error. It is given by

$$\boldsymbol{G}_m = [\boldsymbol{V}_{t-\tau}^H \boldsymbol{H}_t^H \boldsymbol{H}_t \boldsymbol{V}_{t-\tau} + \sigma_n^2 \boldsymbol{I}_{N_t}]^{-1} \boldsymbol{V}_{t-\tau}^H \boldsymbol{H}_t^H \tag{5}$$

At high SNR, $\sigma_n^2 \to 0$ and the MMSE receiver is equivalent to ZF receiver.

III. Efficient Transmission Strategy Against High-Speed Mobility

A. The Proposed Transmission Strategy

According to the analysis in Section II-A, in the mobility environment, the CSI at the transmitter is inevitably outdated because of the mobility aspects and the delay between the uplink estimation of the CSI and the downlink data transmission in TDD systems. And the channel time variations cause the interference among different sub-channels in SVD-based systems. Therefore, we propose a novel processing strategy to remove the sub-channel interference. The capacity and BER performance can be significantly improved even in the high-speed mobility circumstance.

For N_r receiving antennas, the receiving signals can be rewritten as

$$\begin{aligned} \tilde{\boldsymbol{y}} &= \boldsymbol{H}_t \boldsymbol{V}_{t-\tau} \boldsymbol{x} + \boldsymbol{n} \\ &= \boldsymbol{U}_t \boldsymbol{\Sigma}_t \boldsymbol{V}_t^H \boldsymbol{V}_{t-\tau} \boldsymbol{x} + \boldsymbol{n} \end{aligned} \tag{6}$$

where $\boldsymbol{U}_t, \boldsymbol{V}_t, \boldsymbol{V}_{t-\tau}$ are all unitary matrix. The equivalent channel after ideal channel estimation is given by $\boldsymbol{H}_{eq} = \boldsymbol{U}_t \boldsymbol{\Sigma}_t \boldsymbol{V}_t^H \boldsymbol{V}_{t-\tau}$.

According to the above analysis, we attain two propositions.

Proposition 1 *For the time-invariant channel, the receiver shaping filter U_t^H, for conventional SVD-based transmission in Eq.*(2)*, can be obtained by utilizing the QL decomposition to H_{eq}.*

Proof: By QL decomposition, the equivalent channel can be represented as

$$H_{eq} = U_t \Sigma_t V_t^H V_{t-\tau} = QL \tag{7}$$

where $Q \in \mathbb{C}^{N_r \times N_t}$ is a unitary matrix and $L \in \mathbb{C}^{N_t \times N_t}$ is a lower triangular matrix with real diagonal elements. If the channel is invariant, that is $V_t^H V_{t-\tau} = I$, we obtain

$$Q = U_t, L = \Sigma_t \tag{8}$$

$$U_t^H = Q^H \tag{9}$$

■

Thus, for the time invariant channel, we provides a much lower low complexity receiver for conventional SVD transmission by utilizing QL decomposition of H_{eq}.

Proposition 2 *The SVD based precoding at the transmitter actualize the optimal ordering of the SIC at the receiver when perfect CSI is available at the transmitter.*

Proof: After QL decomposition, the detection can be done by successive interference cancelation (SIC). For SIC detection, the detection sequence is crucial due to the risk of error propagation. Considering Eq.(8) $L = \Sigma_t$ and owing to the properties of SVD, we have $l_{11} \geq l_{22} \cdots \geq l_{N_t N_t}$. l_{kk} denotes the k-th diagonal element of matrix L. And the SNR of layer k is determined by the diagonal element $|l_{k,k}|^2$, so SNR of the detection layers also follows : $SNR_1 \geq SNR_2 \cdots \geq SNR_{N_t}$. Thus SIC detection is proceeded from the sub-channel with the higher SNR to the sub-channel with lower SNR. Hence we can attain the optimal detection sequence. ■

Remarks: It should be noted that QL decomposition discussed in the above process can not be replaced by QR decomposition. Because the Eq.(8) is only valid for QL decomposition and does not hold for QR decomposition.

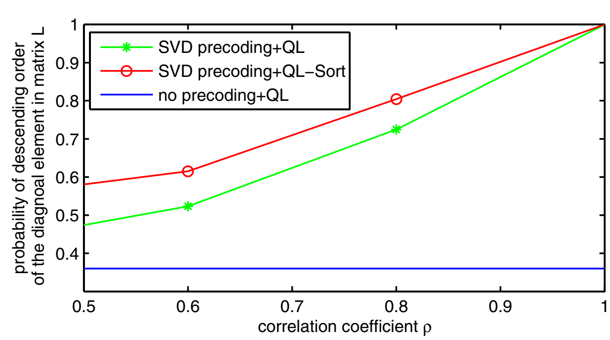

Fig. 2. Probability of descending order of the diagonal element in matrix L

Motivated by the fantastic propositions we draw above, an efficient SVD-based transmission strategy against high speed mobility can be developed. As for time-variant channel, CSI at transmitter is outdated. The off-diagonal elements are not zero any more. So SIC detection is utilized to cancel subchannel interference. If the channel varies slowly in time, the descending order property of diagonal elements of L is satisfied in a large probability. Thus the optimal detection order can be guaranteed in a large scale to avoid error propagation. And the subchannel interference caused by the imperfect CSI at the transmitter can be fully eliminated. As the correlation coefficient decreases, the probability of descending order degrades sharply. In the high-speed mobility environment, the appropriate detection order is no longer guaranteed. Thus, the performance degrades severely due to the error propagation. By utilizing the Sorted-QL decomposition [7], the good detection order can be guaranteed in an acceptable level. The descending property of diagonal element of L is illustrated in Fig.2.

To further improve the performance, we may extend the channel with respect to MMSE criterion. Compared with ZF criterion, the extended MMSE scheme will achieve better performance since the suppression of the noise enhancement. Overall, the procedures of the proposed scheme are as follows.

The precoding is done at the pilot stage to actualize the detection ordering at the transmitter. The pilot is precoded to obtain the equivalent channel. Then we extend the channel matrix according to the MMSE criterion. Further, the sorted QL decomposition is done to the extended equivalent channel as (for notation brevity, we drop off the time index)

$$\underline{H} = \begin{bmatrix} H_t V_{t-\tau} \\ \sigma_n I_{N_t} \end{bmatrix} = \underline{Q}\,\underline{L} = \begin{bmatrix} Q_1 \\ Q_2 \end{bmatrix} \underline{L} \tag{10}$$

After the sorted QL decomposition, multiplying the received signal with Q_1^H yields the estimation of transmit vector y

$$\begin{aligned} y &= Q_1^H \tilde{y} = Q_1^H (H_{eq} x + n) \\ &= \underline{L} x + \tilde{n} \end{aligned} \tag{11}$$

where $\tilde{n} = -\sigma_n Q_2^H x + Q_1^H n$. Finally, the SIC procedure can be expressed as

$$\begin{aligned} \hat{x}_j &= \mathbb{Q}(y_j - \sum_{k=1}^{j-1} L_{jk} \hat{x}_k) \quad (j = 1, 2, \cdots, N_t) \\ &= \mathbb{Q}(x_j + \sum_{k=1}^{j-1} \frac{L_{jk}}{L_{jj}} (x_k - \hat{x}_k) + \frac{1}{L_{jj}} \tilde{n}_j) \end{aligned} \tag{12}$$

where $\mathbb{Q}$ stands for hard decision operation.

B. SINR and Capacity Analysis

The SINR and capacity expressions for conventional SVD-based transmission, 'SVD+ZF', 'SVD+MMSE' and proposed transmission are derived in the following. Through the paper, we assume uniform power allocation among all the sub-channels.

1) Conventional SVD-based transmission: According to Eq.(3), the SINR of j-th layer can be expressed as

$$SINR_j = \frac{|\boldsymbol{\Sigma}_t \boldsymbol{\Omega}|_{jj}^2}{\sum\limits_{k \neq j} |\boldsymbol{\Sigma}_t \boldsymbol{\Omega}|_{jk}^2 + \sigma_n^2} \tag{13}$$

2) SVD+ZF: For ZF criterion, there is no interference among the sub-channels, we can acquire the SINR for j-th sub-channel as

$$SINR_j = \frac{1}{\sigma_n^2 [(\boldsymbol{H}_t \boldsymbol{V}_{t-\tau})^H (\boldsymbol{H}_t \boldsymbol{V}_{t-\tau})]_{jj}^{-1}} \tag{14}$$

3) SVD+MMSE: The filter matrix is shown as Eq.(5), and the SINR of the j-th sub-channel is presented by

$$SINR_j = \frac{[\boldsymbol{G}_m \boldsymbol{H}_t \boldsymbol{V}_{t-\tau}]_{jj}^2}{\sum\limits_{k=1,\cdots,N_t k \neq j} [\boldsymbol{G}_m \boldsymbol{H}_t \boldsymbol{V}_{t-\tau}]_{jk}^2 + \sigma_n^2 \|\boldsymbol{G}_m\|_j^2} \tag{15}$$

4) Proposed: According to Eq.(12), the residual interference of j-th sub-channel can be written as

$$P_{in-j} = \sum_{k=1}^{j-1} \mathbb{E}\left(\frac{|L_{jk}|^2}{L_{jj}^2} |\hat{x}_j - x_j|^2\right) \tag{16}$$

The effective noise power of the j-th sub-channel is given by

$$P_{no-j} = [\mathbb{E}(\frac{1}{L_{jj}} \boldsymbol{n}\boldsymbol{n}^H)]_{jj} = \frac{\sigma_n^2}{L_{jj}^2} \tag{17}$$

From Eq.(16) and Eq.(17) we obtain the SINR of the j-th sub-channel as

$$SINR_j = \frac{L_{jj}^2}{\sum\limits_{k=1}^{j-1} L_{jk}^2 \mathbb{E}(|\hat{x}_j - x_j|^2) + \sigma_n^2} \tag{18}$$

When the detection is free of error propagation, the receiver completely eliminates the sub-channel interference.

To assess the overall performance of the proposed MIMO transmission strategy, we rely on the capacity. The capacity of the $N_r \times N_t$ MIMO system($N_r \geq N_t$) is given by [8]

$$C = \sum_{j=1}^{N_t} \log_2(1 + SINR_j) \tag{19}$$

$SINR_j$ for various schemes are given by Eq.(13), Eq.(14), Eq.(15) and Eq.(18) respectively.

IV. Numerical Results

In this section, numerical results are presented to demonstrate the advantages of the proposed scheme over the existing transmission approaches. Computation effort is also derived.

A. Capacity Performance

Fig.3 shows the capacity performance comparison of the five SVD-based transmission schemes. In the simulation, we consider a MIMO system with $N_t = 8$ and $N_r = 8$ antennas and QPSK modulation. The relationship of the total average capacity and the correlation coefficient ρ is illustrated. With perfect CSI at the transmitter, the channel can be decoupled into independent sub-channels without any interference. Hence the performance of the five schemes is identical. As ρ decreases, the sub-channel interference increases and the capacity performance degrades consequently. The proposed transmission strategy outperforms all the other scheme since the further depression of the sub-channel interference and the proper detection order. While the conventional SVD-based transmission has the worst capacity because it suffers from severe sub-channel interference without any cancelation.

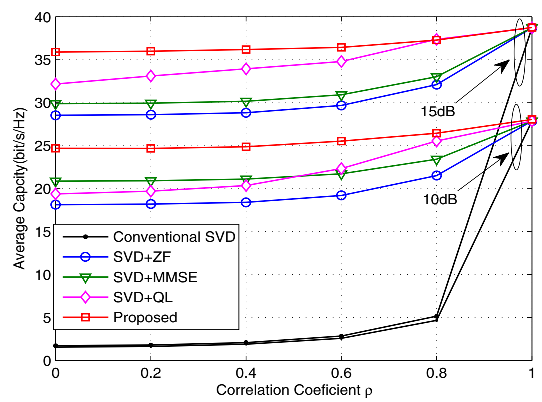

Fig. 3. comparison of capacity performance

B. BER Performance

Fig.4 evaluates BER performance comparison in the case of $N_t = 4$ and $N_r = 4$, QPSK modulation without coding in Rayleigh fading channel. The proposed approach performs much better than the existing schemes. Meanwhile, due to the interference caused by channel variations, BER performance degrades as ρ decreases. We notice that there is a turning point at $\rho = 0.8$. The reason is as ρ approaches 1, the gain of the worst subchannel approaches the minimum singular value of channel matrix. The BER of the worst subchannel will significantly decrease the average BER of all subchannels. And for the proposed scheme, BER attains the best performance as ρ close to 0.8. The reason is, in such case, the diagonal elements of the matrix $\boldsymbol{L}$ happen to be identical. Then the proposed transmission is equivalent to GMD (Geometric Mean Decomposition) transceiver [9].

C. BLER Performance in practical TD-LTE system

Here we apply our proposed scheme in practical TD-LTE system and evaluate the BLER (Block Error Rate) performance. The main parameters in the simulation are p-resented in Table I. As for Frame structure of configuration 2 [10], the channel correlation for EVA-70Hz (33Km/h) is

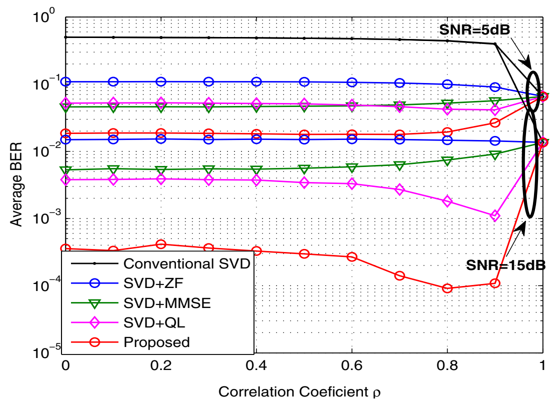

Fig. 4. Comparison of BER performance

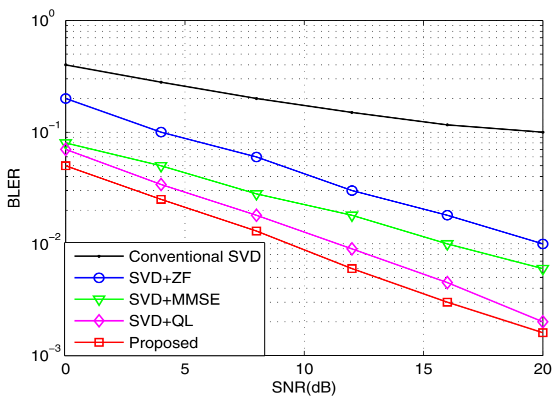

Fig. 5. BLER performance comparison in TD-LTE systems

TABLE I
SIMULATION PARAMETERS IN TD-LTE SYSTEMS

Frame Structure	Configuration 2 [10]
Transmission Bandwidth	20MHz
Carrier Frequency	2.3GHz
Number of IFFT/FFT points	2048
Data Modulation	QPSK
Antennas	$N_t = 2, N_r = 2$
Channel Coding	Turbo coding(Rate=1/3)
Channel Profile	EVA-70Hz [11]

$\rho = J_0(2\pi \times 70 \times 0.003) = 0.61$. Fig.5 presents the BLER comparison results. The proposed scheme outperform the other methods. This indicates that the proposed scheme is feasible and effective for the practical TDD system.

D. Computation Effort

Here we investigate the computational effort of the proposed scheme. The floating point operations (flops) are specified according to the number of transmit and receive antennas. For simplicity, we count each complex addition, multiplication and division as two flops, six flops and ten flops, respectively. As for $N_r \times N_t$ matrix, SVD decomposition takes $4N_t^2N_r + 8N_tN_r^2 + 9N_t^3$ flops and QL decomposition takes $2N_t^2N_r$ flops [12]. For simplicity, the computation complexity of complex matrix can be approximated as six times that of real counterparts. Since the same procedure at the transmitter, we just consider the receiving computation complexity. The computational complexity in terms of flop point operation is summarized in Table.II. For $N_t = 8, N_r = 8$, the computation complexity for the above four schemes are 65280, 17664, 18048, 7248 and 7920 flops. The proposed scheme gets the second lowest computation effort, just a little higher than SVD+QL, but with the profit of better performance.

TABLE II
COMPUTATIONAL COMPLEXITY COMPARISON

Conventional SVD	$24N_tN_r^2 + 48N_t^2N_r + 54N_t^3 + 12N_r^2 - 6N_r + 6N_t$
SVD+ZF	$12N_t^3 + 24N_t^2N_r - 18N_t^2 + 6N_tN_r$
SVD+MMSE	$12N_t^3 + 24N_tN_r^2 - 12N_r^2 + 6N_tN_r + 6N_r - 6N_t$
SVD+QL	$12N_t^2N_r + 12N_t^3 + 6N_t^2 - 6N_r$
Proposed	$12N_t^2N_r + 12N_r^3 + 18N_t^2 - 6N_r - 12N_t$

V. SUMMARY AND CONCLUSION

In TDD systems, the transmitter can make use of channel reciprocity to obtain the CSI for SVD-based transmission. In practical systems, however, conventional SVD-based transmission usually suffers dramatical degradation from the time variations of the channel. This paper proposed an efficient transmission strategy against high-speed mobility in TDD MIMO systems. Compared with the existing methods, the proposed scheme achieves much better performance both in capacity and BER with much lower computation complexity. Simulation results show that the proposed scheme can efficiently reduce the effect of the CSI impairment at the transmitter caused by channel variation.

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