Comparative Analysis of Pilot-Based Channel Estimation Schemes for Massive MIMO

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Abstract: For the improvement of spectral and energy efficiency in multi-user multi-cell MIMO systems, Channel Estimation is crucial. Multi-cell minimum mean square error (M-MMSE) scheme is proposed in this work for the channel estimation of massive multiple-input-multiple-output (MIMO) networks, which includes an uplink MMSE detector and a downlink MMSE method. Contrary to conventional single-cell schemes that suppress interference using only channel estimates for intra-cell users, our scheme shows the optimal way to suppress both intra-cell and inter-cell interference instantaneously by fully utilizing the available pilot resources.

Keywords: MIMO, multi-user, multi-cell, M-MMSE, inter-cell interference, intra-cell interference

I. INTRODUCTION

In the uplink reception and downlink transmission, the most common processing schemes are matched filtering (MF), zero-forcing (ZF), maximum ratio combining (MR) and minimum mean square error (MMSE) processing, where the latter is also referred to as single-cell MMSE (S-MMSE) [1]. In these schemes the Base Station (BS) only utilizes the instantaneous realizations of the channels to its own intra-cell users when creating the estimators, while users in other cells are either neglected or only considered based on their long-term statistics [4]. In this work, multi-cell scenarios are explored where the pilot signals are not reused in every cell. The pilot sequences are exploited at each BS to actively suppress both intra-cell and inter-cell interference. It brings significant SE gains over conventional single cell schemes [2][3][5].

II. FRAMEWORK, METHODS AND TOOLS

The framework, methods and tools used in the research to obtain data, analyze data, obtain results and derive conclusions are detailed in this section.

A. *Research Framework*

A simulation setup with 16 Base Stations is considered. Each cell is placed on a grid of 4x4 cells and has a square area of 0.25 km x 0.25 km. In each cell, the User Equipment are dispersed uniformly and independently at random distances from the Base Station. A wrap-around topology is used to simulate that all BSs experience the same amount of interference from all directions. For each combination of UE and BS, eight alternative locations are considered to determine which one has the shortest distance to the UE. For calculating the nominal angle between the UE and BS as well as the large-scale fading, the BS with the shortest distance is taken into account.

A cellular network with L cells, each consisting of one BS at its center with M co-located antenna elements and K randomly located single antenna users is considered as a system model. The channel between the user and antenna is assumed to be Rayleigh fading.

B. *Methods and Tools*

This project uses Monte Carlo methodology to generate the simulation results of the comparison of different receiving schemes [1]. Following is the methodology followed to generate the result:

Macroscopic propagation effects,

1. Randomly drop UEs in each cell
2. Compute distances and nominal angles
3. Generate random shadow fading coefficients
4. Compute average channel gains, spatial correlation matrices and estimation error correlation matrices.

Microscopic propagation effects,

1. Generate random estimated channel vectors

SE computation

1. Compute receive combining vectors and resulting SINR.
2. Compute "instantaneous" Spectral Efficiency
   $SE_{jk}^{UL,inst.} = \tau_u/\tau_c log_2(1 + SINR_{jk}^{UL})$
   Where, τ_c is complex valued samples, given by $\tau_c = B_c T_c$, here, B_c refers to coherence bandwidth and T_c refers to coherence time; and τ_u refers to UL data signal
3. Average instantaneous SINR over estimated channels to obtain spectral efficiency.
4. Obtain simulation results by considering the SEs of all UEs for different shadow fading realizations and UE locations.

The mathematical models for the channel estimation schemes are expressed in terms of line graphs by the use of MATLAB software.

III. DATA ANALYSIS AND RESULTS

A. *Data*

In this research work, 16 base stations with ten user equipment each are considered. The simulation is performed for the universal pilot reuse factor, with the transmission bandwidth set to $200 * 10^6\,Hz$. Both the uplink and downlink transmission powers are adjusted to 100 mW, with a background noise of -94 dBm taken into account. The simulation parameters are set in accordance with the reference [1].

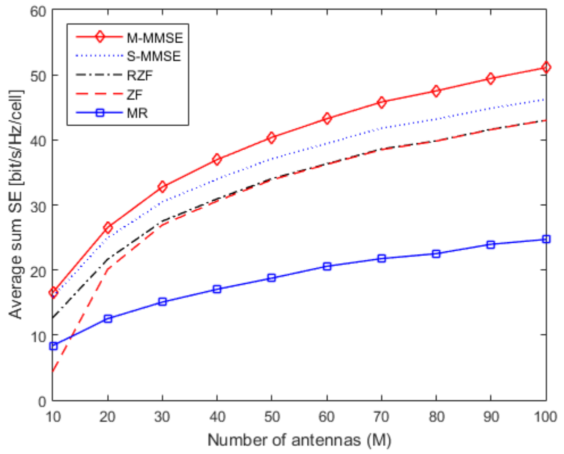

Fig.1: Average Spectral Efficiency at f=1 pilot reuse factor for number of base station antennas and K=10 UEs

TABLE I: SUMMARY OF SIMULATION RESULTS

Scheme	Pilot Reuse Factor
	f = 1
M-MMSE	51
S-MMSE	47
RZF	42
ZF	42
MR	25

The table above summarizes the average SE of all channel estimation schemes at f=1.

B. *Data Analysis Tools and Techniques*

The mathematical models for the channel estimation schemes are expressed in terms of line graphs by the use of MATLAB software. The complexity of computing the combining matrix once per coherence block is taken into consideration. The combining matrix is computed by using matrix-matrix multiplication and matrix inversion, where it is concluded that complex multiplications and divisions dominate the complexity, while additions and subtractions can be neglected. The data is analyzed on the basis of complexity, number of base stations used and the behavior of average spectral efficiency as the number of base stations increase.

C. *Analysis Results*

Figure 1 above shows the average spectral efficiency of the Base Station antennas for universal pilot reuse with f = 1. The highest spectral efficiency as shown in the figure above is provided by M-MMSE. If we attempt to reduce the complexity of M-MMSE and choose other precoding schemes, the SE is reduced slightly with each estimate. The S-MMSE scheme offers SE that is 5%–10% greater than RZF and ZF, but lower than M-MMSE. The SE with ZF degrades quickly for M<20 because the BS lacks sufficient degrees of freedom to cancel the interference without also canceling a significant portion of the desired signal. It should be noted that RZF and ZF give essentially the same SE in the range M>20, which is of primary interest in Massive MIMO. Even though MR only offers half the SE of the other schemes, from the simulation result above we also know that it is 10% less complex than RZF and does not require matrix inversions.

IV. CONCLUSION AND FUTURE WORKS

In conclusion, the uplink M-MMSE detector and downlink M-MMSE precoder brings very promising sum SE gains over S-MMSE and other single-cell schemes by actively suppressing both intracell and inter-cell interference. This scheme is extremely useful in determining the correct Channel State Information as compared to the single-cell schemes. However, this advantage of M-MMSE comes with complexity. The performance of the proposed channel estimator is analyzed by varying the number of antennas/base stations for single pilot reuse factor and it can be concluded that three combining techniques M-MMSE, MR and RZF could be considered for channel estimation in different scenarios. M-MMSE gives the highest SE with the most complexity, so it is ideal to use M-MMSE technique for universal pilot reuse factor. MR technique has the least complexity but also provides the lowest spectral efficiency of all, and finally RZF technique which balances between complexity and spectral efficiency. For further study, the channel can be estimated more accurately using deep learning methods.

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