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Spectral Efficiency Performance Analysis of UL Linear Precoding in Massive MIMO Systems with S-MMSE and M-MMSE

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Abstract

The 5G network encompasses a set of technologies corresponding to the fifth generation of the standard for mobile telephony. It is validated by the ITU, the International Telecommunication Union. Among these technologies is massive MIMO. The most important concern is improving spectral efficiency. Massive MIMO systems use large arrays of antennas at the base station to transmit multiple users on the same time-frequency resource. The goal of this paper is to maximize the spectral efficiency with linear precoding. In this work, we analyzed the performance and the effect of the minimum mean square error (MMSE), which is a technique of linear precoding on the massive MIMO uplink spectral efficiency in two scenarios: single-cell and multi-cell. We have focused the multi-cell for the reason that it suffers from pilot contamination problems. Orthogonal pilot sequences have to be reused among cells; this leading to estimation errors of channel state information in both the transmitter and the receiver, The MMSE technique is used to overcome the interference that limits the spectral efficiency for massive MIMO system. We apply two MMSE algorithms explicitly S-MMSE and M-MMSE.

Keywords: 5G, massive MIMO, spectral efficiency, pilot contamination.

1. Introduction

Massive MIMO is a promising technology in wireless communication that increases spectral efficiency (SE) to compared to MIMO systems [1]. Massive MIMO employs base stations equipped with a large number of antennas and which serves several users with a single antenna at the same frequency and time resources [2-3]. However, in massive MIMO systems a high number of antennas simultaneously serve a much smaller number of terminals. The number of terminals that can be served simultaneously is limited but not because of the number of antennas, but because of our inability to obtain the channel information for an unlimited number of terminals, This paper analyses the optimization of Spectral Efficiency through antenna selection schemes such as precoding, and the effect on the performance of the massive MIMO systems for the future 5G technology.

The massive MIMO system can work with a single-cell or multi-cell system, the single-cell system consists of BS equipped with a large number of antennas while the multi-cell system is composed of many single-cell systems interconnected between them [4]. One of the main problems of massive MIMO uplink system is users interference which leads to a lack of data transmission and waste of power transmission. Therefore, the interference to be eliminated at the BTS level. One of the important methods used to reduce interference is the linear precoding techniques that arrive in the transmitter before it is sent over the channel [5]. Linear precoding technology is a hot and effective topic in massive MIMO systems [6-7]. Linear precoding techniques have an effective role in improving the error rate using ideal channel estimates CSI (channel state information). According to studies carried out in the literature, it can be concluded that pre-coding is less complicated in terms of calculations compared to non-linear pre-coding which has a high mathematical complexity in transmission stations and user devices [8]. Minimum mean-squared error (MMSE) technique has been studied to know the large antenna limit in terms of combining/precoding in a single-cell scenario [9-10]. MMSE was studied in a multicellular scenario in (M-MMSE) [11-12]. M-MMSE differs from S-MMSE in the channel estimation process, The first technique uses BS channel estimates from UEs in all cells, While S-MMSE channels are estimated between the base station and the user in the special cell. Pilot contamination is a significant limitation of the massive MIMO performance in a multicell scenario, this problem was considered in [3-13-14]. Fig. 01 represents the concept of pilot contamination. (A) Uplink Transmission. (B) Downlink transmission. This paper is organized as follows. A brief System model of UL massive MIMO is presented in Section II. Section III demonstrates the average spectral efficiency. Simulation results and discussion are presented in Section IV. Conclusions presented in Section V.

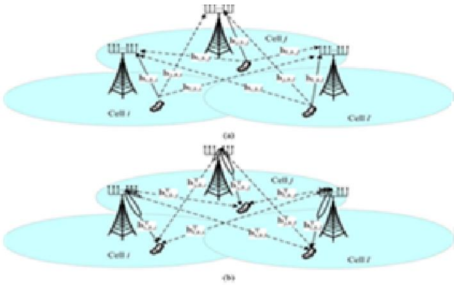


Fig.1. Illustration of the concept of pilot contamination. (A) Uplink Transmission. (B) Downlink transmission.

2. System model of UL massive MIMO

In the following section a detail of our system model is presented, followed by a description of the two state of the art variations of the MMSE combining vector, S-MMSE and M-MMSE.

2.1. Single-Cell Uplink System Model

We consider that the uplink transmissions of a TDD-cell system in which a base station is configured with M antennas to serve up simultaneously K single antenna users, the signal received from the base station (BS) can be expressed as [15]:

$$Y = \sqrt{\frac{Pu}{M}} Hx + n \tag{1}$$

where $X \in C^{K \times L}$ is a training signal matrix, each row of the matrix corresponding to the training data of each L long pilot symbol launched by the user, The channel matrix $H \in C^{M \times K}$ represents the determined channel parameters to be estimated, $n \in C^{M \times L}$ denotes additive white Gaussian noise (AWGN). Fig. 02 illustrates, the considered uplink single-cell massive MIMO system..

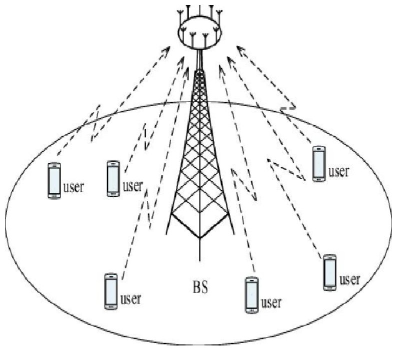


Fig. 2. The considered uplink single-cell massive MIMO system..

2.2.1. Multi-Cell Uplink System Model

This network includes L cells, each cell has K single-antenna users, and the number of antennas at each base station is M, We expand our study of both traditional and statistical compound charts into a multi-cell scenario defining the UL system model in a multi-cell scenario [16]:

$$y_j = \sum_{l=1}^{L} \sum_{k=1}^{K_l} \sqrt{P_{lk}}\, h_{jlk} s_{lk} + n_j \tag{2}$$

where $n_j \sim N_c(0_{Mj}, \sigma_{UL}^2 I_{Mj})$ is independent additive receiver noise with zero mean and variance σ_{UL}^2, the UL signal from UE *k* in cell *l* is denoted by $s_{lk} \in \mathbb{C}$. Fig. 3. represents the description of uplink multi-cell massive MIMO system.

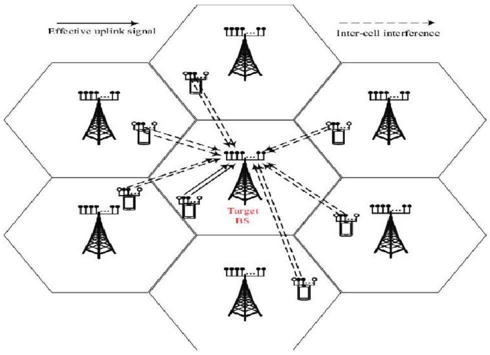


Fig. 3. Description of uplink multi-cell massive MIMO system.

3. Average Spectral efficiency

The spectral efficiency indicates the average number of bits transmitted in each of the complex samples, so the unit of measurement is bits per second per Hertz or bits / s / Hz.

A fundamental parameter in any communication system is the channel capacity which determines the maximum possible spectral efficiency, under certain conditions, which guarantees the reliability (low error rate) of the system.

3.1. Single-Cell Uplink System Model

The achievable SE, which focusing the UL is as follows [17]:

$$v_{jk}^{H}y_{j}=v_{jk}^{H}h_{jk}^{j}s_{jk}+\underbrace{\sum_{i=l,i\neq k}^{K}v_{jk}^{H}h_{ji}^{j}s_{ji}}_{Intra-cell\ interference}+\underbrace{\sum_{l=1,l\neq j}^{L}\sum_{i=1}^{K}v_{jk}^{H}h_{li}^{j}s_{li}}_{Inter-cell\ interference}+\underbrace{v_{jk}^{H}n_{j}}_{Noise} \quad (3)$$

where $n_j \sim N_c(0_M, \sigma_{UL}^2 I_M)$ is independent noise, BS j selects the combining vector $v_{jk} \in \mathbb{C}^M$ which is multiplied with the received signal $y_j \in \mathbb{C}^M$, the data signal from UE k in cell j is denoted by $s_{jk} \sim N_c(0, \rho_{ul})$. If the MMSE channel estimation is used, an UL spectral efficiency of UE k in cell j is [18]:

$$SE_{jk}^{ul}=\frac{\tau_u}{\tau_c}\mathrm{E}\left\{\log_2\left(1+SINR_{jk}^{ul}\right)\right\}\ \text{[bit/s/Hz]} \quad (4)$$

with $\frac{\tau_u}{\tau_c}$ accounting for the fraction of samples used for UL data and

$$SINR_{jk}^{ul}=\frac{p_{jk}\left|\mathrm{E}\left\{v_{jk}^{H}h_{jk}^{j}\right\}\right|^{2}}{\sum_{l=1}^{L}\sum_{i=1}^{K}p_{li}\mathrm{E}\left\{\left|v_{jk}^{H}h_{li}^{j}\right|^{2}\right\}-p_{jk}\left|\mathrm{E}\left\{v_{jk}^{H}h_{jk}^{j}\right\}\right|^{2}+\sigma_{UL}^{2}\mathrm{E}\left\{\left\|v_{jk}\right\|^{2}\right\}} \quad (5)$$

4. Simulation results and discussion

The In this Section, the results obtained from the different simulations that were performed will be reversed. M-MMSE and S-MMSE will be compared in terms of spectral efficiency according to different scenarios, which are the reuse of the pilot f, number of antennas M, and the number of users K. Simulation parameters are summarized in the Table 1.

Fig.4 illustrates, the average SE of the massive MIMO UL system as a function of the number of base station antennas for re-use of the universal pilot with f = 1 , it's shown M-MMSE scenario gives the highest value of spectral efficiency compared to S- MMSE.

Fig.5. shows the average SE with a non-universal pilot reuse f, through the obtained results, we note that the greater the number of pilots f = 2 and f = 4, the greater the spectral efficiency in a multi-cell scenario, because it needs more pilots to overcome the problem of Pilot contamination which limits spectral efficiency, however, the large number of pilots reduces energy efficiency, and this particular problem is the subject of a hot study in the literature, we also notice a decrease in the spectral efficiency of a single-cell scenario because it does not require the pilot reuse factor.

Otherwise, Table 2 summarizes, the average of SE for M = 100 and *K* = 10 for different pilot reuse factors *f*.

Table. 1. Network parameters for SE evaluation

Parameter	Value
Cell area	$1km \times 1km$
Number of cells	L=16
UEs per cell	K=10
Number of antennas	M=100
UL noise power	σ_{UL}^2 = - 94 dBm
Samples per coherence block	τ_c =200
Pilot reuse factor	f =1, 2 or 4
UL transmit power	ρ_{ul} = 20 dBm

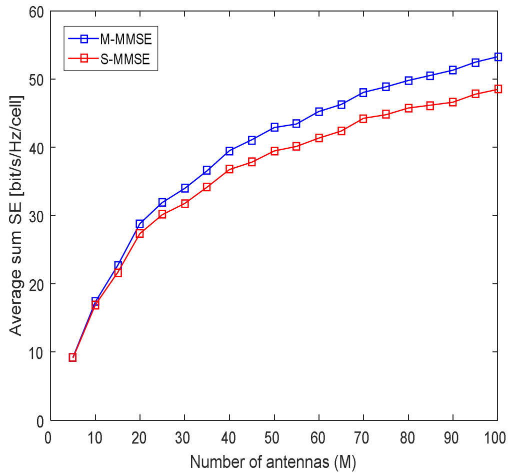
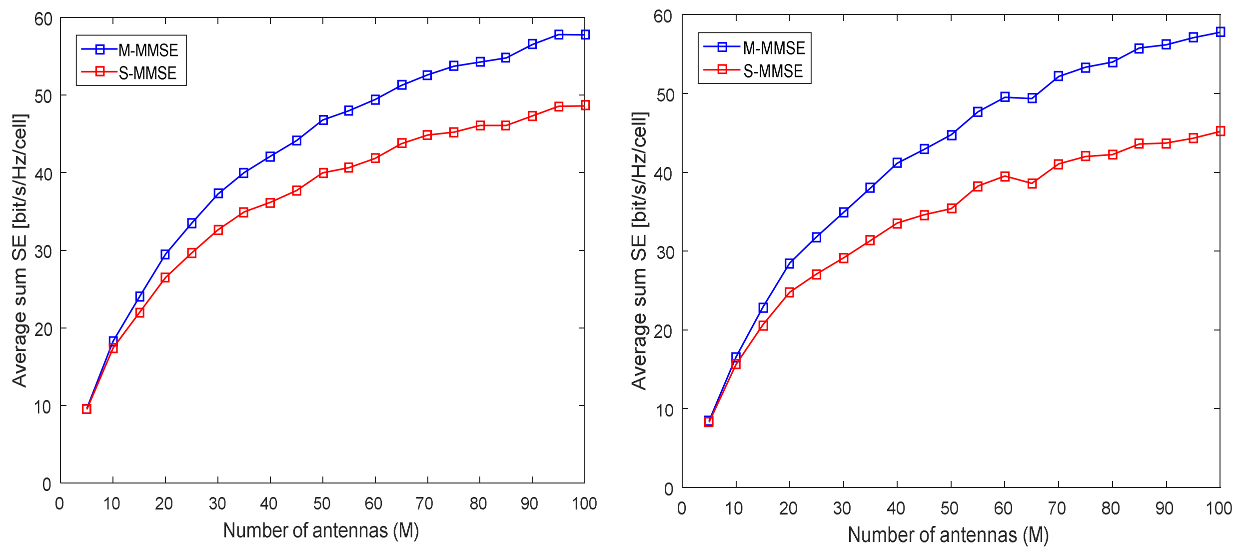


Fig. 4. Average SE for massive MIMO UL system as function of the number of BS antennas for different combining schemes M-MMSE and S-MMSE. K = 10 UEs per cell and the same K pilots are reused in every cell.



(a) Pilot reuse factor $f = 2$ (b) Pilot reuse factor $f = 4$

Fig. 5. Average SE for massive MIMO UL system as a function of the number of BS antennas for different combining schemes M-MMSE and S-MMSE. There are K = 10 UEs per cell with Pilot reuse factor $f = 2$ and $f = 4$.

Table. 2. Average SE for M = 100 and K = 10 for different pilot reuse factors f.

scheme	$f = 1$	$f = 2$	$f = 4$
M-MMSE	53.62	58.71	59.11
S-MMSE	48.56	49.27	45.38

5. Conclusion

Massive MIMO systems can significantly increase the spectral efficiency of mobile network because of its multi-spatial multiplexing strategy, and these characteristics are possible when the base station uses simple signal processing as it in the case of the studied pre-coding techniques which are M-MMSE and S-MMSE, M-MMSE based linear precoding technology works better in terms of spectral efficiency compared to S-MMSE system but it requires reuse of pilot factor to improve spectral efficiency. However, it is the best technology that allows us to increase spectral efficiency in the massive MIMO system.

References

1. Ephraim, Y., & Van Trees, H. L. (1995). A signal subspace approach for speech enhancement. *IEEE Transactions on speech and audio processing*, *3*(4), 251-266.
2. Hu, Y., & Loizou, P. C. (2002, May). A subspace approach for enhancing speech corrupted by colored noise. In *Acoustics, Speech, and Signal Processing (ICASSP), 2002 IEEE International Conference on* (Vol. 1, pp. I-573). IEEE.
3. Loizou, P. C., Lobo, A., & Hu, Y. (2005). Subspace algorithms for noise reduction in cochlear implants. *The Journal of the Acoustical Society of America*, *118*(5), 2791-2793.
4. Ghasemi, J. (2011, March). A new approach based on SVD for speech enhancement. In *Signal Processing and its Applications (CSPA), 2011 IEEE 7th International Colloquium on* (pp. 371-376). IEEE.
5. Doclo, S., & Moonen, M. (2002). GSVD-based optimal filtering for single and multimicrophone speech enhancement. *IEEE Transactions on Signal Processing*, *50*(9), 2230-2244.
6. Hermus, K., & Wambacq, P. (2006). A review of signal subspace speech enhancement and its application to noise robust speech recognition. *EURASIP Journal on Advances in Signal Processing*, *2007*(1), 045821.