Precoding Technique for Optimum Spectral Efficiency in Massive MIMO System

Abstract— Massive MIMO is used in a new generation wireless technology and a method to improve the spectral efficiency (SE) of communications systems. Nowadays, because of the users and applications that are always increasing day by day the improvement of wireless technology shall be in line according to demand. In this paper, precoding technique used to optimize spectral efficiency and the number of user as a function of the number of antenna with different interference condition are investigated. From the simulation, SE per cell for precoding technique and corresponding number of scheduled users K* can be seen. As the number of antenna at base station (BS), M increase the SE will increasing. The K* depends on the intercell interference condition strongly.

Index Terms— precoding technique, spectral efficiency, massive MIMO, base station, intercell interference, scheduled users.

I. INTRODUCTION

Multiple Input Multiple Output (MIMO) is a system for wireless communications that refers to links for which the transmitting and receiving elements are fitted out with multiple antennas [1]. The transmit antennas on one end and the received antenna on the other end are combined so that the errors can be minimized or the data rate of the communication is improved. MIMO is also one of smart antenna technology and now massive MIMO used as the improvement of the existing system [2], [5].

The high capacity and faster data transmission with minimum losses and error are actually the priority of the wireless communication system for nowadays. In several years to come, the capacity of the wireless network will be more congested than now. Because of that, the system with new technique are needed to snuff this problem out. Massive MIMO is one of the smart technique that can provide promising approaches. Basically, spectral efficiency and the number of user per cell influenced by the number of antenna at base stations (BS). In contrast, when the spectral efficiency improved the channel capacity of the system is also increases. Indirectly, the performance of the wireless communication system will be improved [3].

Massive MIMO system is a new technology upgraded from the conventional MIMO system where more than hundreds or thousands antennas used at base station (BS). Basically, this new system widely used in wireless communications to improve the channel capacity besides to reduces the error and costs. In addition, the spectral efficiency will be improved by increasing the number of antennas [2], [11]. Massive MIMO able to use the simple technique processing such as minimum mean square error (MMSE), zero forcing (ZF), and maximum ratio combining (MRC) at the base station and using channel estimation from the uplink. Basically, at high transmission power the ZF performance will be better since the number of antenna increased [15].

Precoding techniques can be simply defined as a process to identify the channel by sending signal code information from transmitter to the receiver. [6], [7]. Basically, by using precoding technique the corrupted effect of the communication channel can be reduced since the receiver does not have to know the channel side information.

Spectral efficiency can be defined as the total number of signal information that can be transmitted from one array to the others. Basically, the MIMO system will increase the spectral efficiency and indirectly data rate of the communication is improved [3], [4]. When the number of antennas increased, massive MIMO system with linear precoding will improve the performance by different parameters. In this paper, spectral efficiency and number of user as a function of the number of antenna with different interference condition will be considered.

ZF precoding is a technique of signal processing where the transmitter antenna can void multiuser interference signal information in wireless communication [8], [12]. In maximal ratio combining (MR) the output is weight sum of all branches are all nonzero [9]. The signals are co-phased before being summed where generally requires an individual receiver and phasing circuit for each antenna elements. From the analysis of the studies in maximal spectral efficiency by using massive MIMO system, the number of user equipment UE and scheduled users, K* that should be scheduled in massive MIMO for a fixed magnitude of antennas are investigated [10].

Basically, high per cell spectral efficiency will be achieved in term of capacity performance by arranging many UE for simultaneous transmission. Pilot Zero Forcing (P-ZF) gives the best performance for each user equipment, while the maximum ratio combining (MR) gives the lowest spectral efficiency per user equipment [10]. However, ZF processing is always the best choice in terms of per cell spectral efficiency compared with P-ZF. This is because inter cell interference by P-ZF is only needed in certain cases with strong inter cell interference.

II. OPTIMIZING NUMBER OF USER IN HEXAGONAL NETWORKS

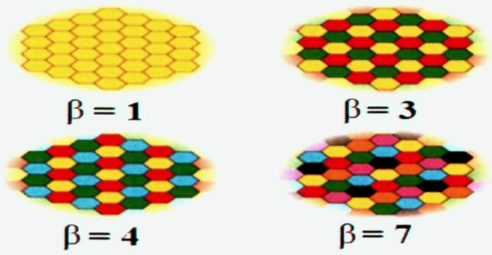


Fig. 1: Hexagonal networks with different pilot reuse factors, β.

The symmetric network topology as shown in Fig.1 with hexagonal cells will be considered in this section. In order to payload data transmission all resources allocated used in all cells all the time. Whereas, to prevent the edge effects and to make sure all cells in same properties the hexagonal grid become very large. The cell radius, r is more than zero and actually it is the range from center of the cell to the angle of the cell. Each cell consists of pair of integer axis 1 and axis 2 as shown in Fig.2 and this pair of integer determine the location of BS. [13].

$$bj = \sqrt{3}\begin{pmatrix} \sqrt{3}r/2 \\ r/2 \end{pmatrix} \alpha j^{(1)} + \begin{pmatrix} 0 \\ \sqrt{3}r \end{pmatrix} \alpha j^{(2)} \in \mathbb{R}^2 \quad (1)$$

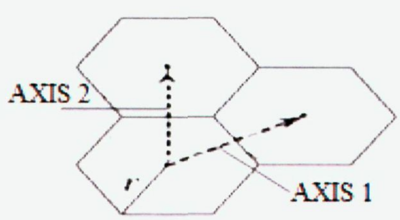


Fig. 2: Hexagonal grid coordinate system.

On the hexagonal grid each cell consists of six interfering cells for the first tier, twelve in the second tier, and so on. As shown in hexagonal networks [14] in Fig.1, this limits which pilot reuse factors that give symmetric reuse patterns β elements of {1, 3, 4,7,9,12,13,....}.

III. OPTIMIZING SPECTRAL EFFICIENCY FOR DIFFERENT INTERFERENCE CONDITIONS

All the spectral efficiency in the cell on the hexagonal grid are simulated and interference is considered negligible. The user can be anywhere in the cells, but it should be at least 0.14r or percentage of the radius inside the cell where no UEs are allowed from the BS in order to make the analysis independent with r. In the uplink (UL) the BS can use its various of antennas for coherent receive combining and downlink (DL) will transmit precoding which can amplifies signal that desired and blocking the interfering signals. UE will send known signals as specified and the pilot signals cannot be avoided affected by intercell interference. That is why the transmission resources are used across cell. The expressions for the per cell SEs with MR, ZF, and P-ZF in the uplink and downlink [10].

$$SE\,(UL) = K\,\zeta\,(UL)\;(1 - B/S)\;\log_2(1 + 1/Ischeme)\;[bit/s/Hz/cell] \quad (2)$$

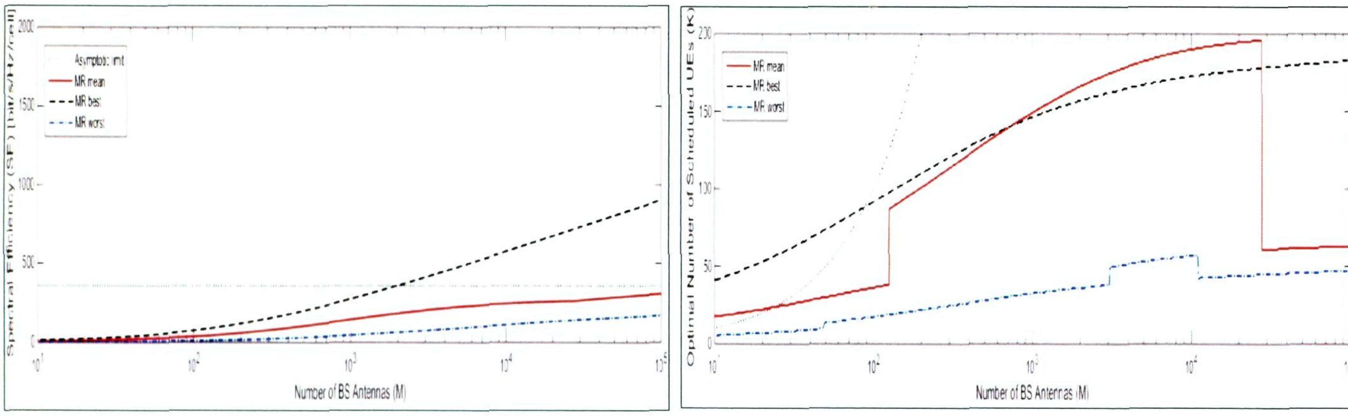
$$SE\,(DL) = K\,\zeta\,(DL)\;(1 - B/S)\;\log_2(1 + 1/Ischeme)\;[bit/s/Hz/cell] \quad (3)$$

This paper considers three types of linear precoding which are ZF precoding that terminate intra cell interference, MR precoding that amplifies the desired signal, and P-ZF precoding that actively rejects both intra cell and inter cell interference. Basically, P-ZF precoding is a fully distributed coordinated beamforming scheme tailored to massive MIMO systems, since each BS only uses locally estimated CSI.

The spectral efficiency will be optimized according to the number of user, K* and all relevant integer values of pilot reuse factor, β for each number of antennas, M. The coherence block length set to S = 400, set the pathloss exponent as k=3.7, and set the signal to noise ratio to ρ/σ^2 = 5 dB.

The environments with three different level of intercell interference consists of best case, average case, and worst case are considered. The parameter values for locations of UE in each cell computed by Monte Carlo simulations.

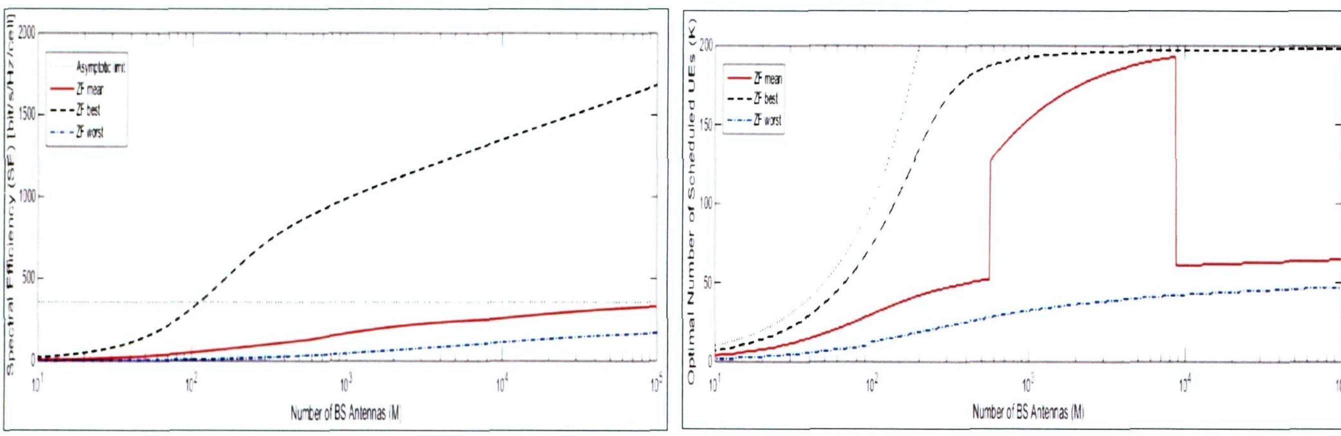
IV. RESULT AND DISCUSSIONS



(a) Optimized spectral efficiency per cell for MR

(b) Optimized number of UEs for MR

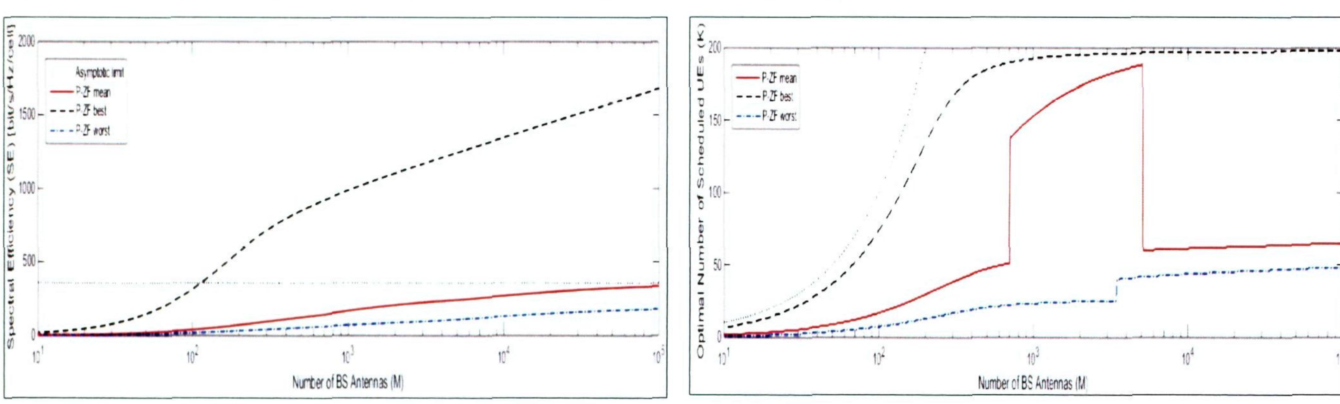
Fig. 3: Simulation of optimized spectral efficiency and optimal number of UE for maximum ratio combining (MR) precoding with different inter cell interference conditions.



(a) Optimized spectral efficiency per cell for ZF

(b) Optimized number of UEs for ZF

Fig. 4: Simulation of optimized spectral efficiency and optimal number of UE for zero forcing (ZF) precoding with different inter cell interference conditions.



(a) Optimized spectral efficiency per cell for P-ZF

(b) Optimized number of UEs for P-ZF

Fig. 5: Simulation of optimized spectral efficiency and optimal number of UE for pilot zero forcing (P-ZF) precoding with different inter cell interference conditions.

This study considers three different propagation environments with different intercell interference conditions. The UE located in all cells uniformly in average case. All UE in other cells located at the cell edge furthest from BS in best case. While UE in other cells are located at the edge closest to BS in worst case.

The best case is convincing since the UE positions in the interfering cells are not same with respect to different cells. The worst case is pessimistic since the UE cannot all be at the worst locations and with respect to all other cells at the same time. While the average case can be the most applicable in practice since the averaging comes from UE mobility, scheduling, and random switching of pilot sequences between the UE in each cell.

Overall the spectral efficiency in simulations increase when increasing the number of antennas at all inter cell interference conditions for MR, P-ZF, and ZF as shown in Fig.3a, Fig.4a, and Fig.5a respectively. However, ZF is corresponding to P-ZF in the best case. In contrast, at worst case P-ZF excels compared with ZF. In the best case inter cell interference, ZF performance for spectral efficiency is higher compared with MR. This is because of the potential to decrease the intra cell interference is very high. But in the average case the optimized SE are quite same for all the types of linear precoding.

Basically, the number of UE, and the pilot reuse factor β that are used in the system influenced the performance of the spectral efficiency. The channels become more orthogonal when M larger and the number of K* increase. This situation take place when the magnitude of β become smaller.

Reuse factor is an integer that when β smaller the K* will be larger. MR gives the largest number of K* and switches to a smaller reuse factor at antennas. While the P-ZF gives the smallest number of K* and has the large reuse factors since it can suppress more inter cell interference in all cases. Shortly, ZF and P-ZF give higher per user SE to fewer UEs, while MR gives low per user SE to many UEs.

V. CONCLUSION

This paper investigated how to optimize spectral efficiency and the number of user as a function of the number of antenna with different inter cell interference conditions by using precoding technique. In a nutshell, high per cell SEs achieved by scheduling many UEs for simultaneous transmission. P-ZF gives the highest performance per UE in term of spectral efficiency. While MR shows the lowest SE per UE. On the other hand, MR schedules the largest number of UE and P-ZF the smallest number of UE. But overall shows the ZF processing is always the best choices in term of per cell SE. Based on the simulations shows that the pilot reuse of β=3 is always a good choice. Thus, when M and K* increase the reuse factor will be decrease.

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