Published by :
http://www.ijert.org

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 6 Issue 09, September - 2017

Massive MIMO: Maximal User Allocation with Uniform Power for Enhancement of Spectral Efficiency

Shruti Tiwari, ME Scholar
Electronics and Communication
UIT RGPV
Bhopal (M.P.) India

R. K. Chidar, HOD
Electronics and Communication
UIT RGPV
Bhopal (M.P.) India

***Abstract*— New network generation needs to cope with demand of high area throughput to manage with the growing wireless data traffic. Previous network generations resulted improvement in area throughput by cell densification and allocation of more bandwidth. Further cell densification is complex and it appears that a saturation point is reached. Valuable frequency bands below 6 GHz provide good network coverage and service quality. Higher bands work well for short range line-of –sight conditions. So we cannot expect major bandwidth improvements. Earlier network generations has not seen any improvements in spectral efficiency (bit/s/Hz/cell). This paper describes the physical layer technology for Massive MIMO to improve the spectral efficiency for future 5G networks.**

***Keywords*— MU-MIMO, spectral efficiency, multi cell, throughput, reuse factor, physical layer, power allocation**

I. INTRODUCTION

Wireless data traffic has doubled every two years since the beginning of wireless communications. Different technologies have dominated in previous network generations. Current exponential growth in cellular networks is driven by wireless data traffic. It seems that this trend will not break. Even the well reputed Cisco Visual Networking and Ericsson Mobility's Report have indicated faster growth rate than the expected rate by Martin Cooper.

Evolving 5G technologies need to focus on improving the area throughput to keep up the growth rate in wireless data traffic. The area throughput for wireless network is measured in bit/s/Km^2 and is modelled as-

*Area Throughput (bit/s/Km^2) = Bandwidth (Hz) * Cell density (cells/ Km^2) * Spectral Efficiency (bit/s/Hz/cell)*

Three main components that can be improve to have high area throughput are

- Allocation of more bandwidth for 5G services.
- Cell densification by adding more independent cells.
- Improving data efficiency per cells for a given amount of bandwidth.

Previous network generations have not seen any improvement for spectral efficiency (SE). This factor in future might become the primary way to achieve high area throughput for 5G networks.

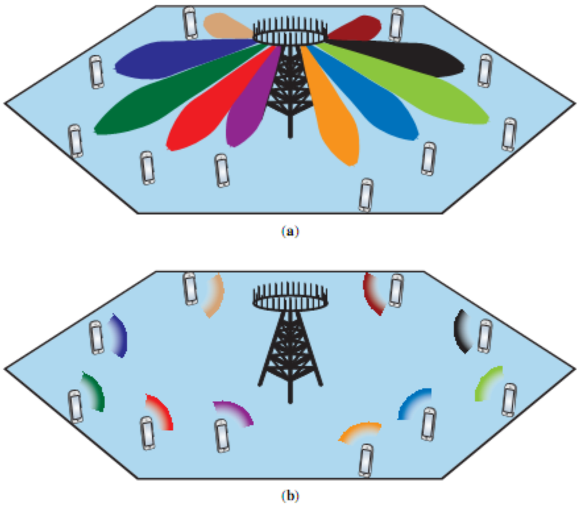
A. Multi-User Multiple Input Multiple Output (MU-MIMO)

Spectral efficiency of a single input single output (SISO) channel is upper bounded by the Shannon capacity given as $\log_2(1+\overline{SNR}) bit/s/Hz$ for additive white Gaussian noise (AWGN) channels. Capacity is a logarithmic function of SNR denoted by $\overline{SNR}$. Thus to increase the capacity, increase in $\overline{SNR}$ is required, which corresponds an increase in transmitted signal power. For example, a system operating at 2 bit/s/Hz needs to double its spectral efficiency to 4 bit/s/Hz. This corresponds improving SNR by a factor of 5, from 3 to 15. This example clearly indicates that the logarithm of the SE forces us to increase transmitted power exponentially to achieve a linear increase in SE for SISO channels. This method is highly inefficient and non-scalable. It gets worsen due to interfering transmission from other cells as other users scale their transmit power.

Traditionally, the time/frequency resources have been divided into resource blocks with only one user terminal active per block. Thus the terminal receives single data stream with an SE as $\log_2(1+\overline{SNR}) bit/s/Hz$. Multiple parallel transmission increases SE efficiently. Suppose there are G parallel transmissions, then the sum SE becomes $G\log_2(1+\overline{SNR}) bit/s/Hz$ with G as a multiplicative pre log factor. Parallel transmission can be realized as two distinct cases-

- Point-to-point MIMO [2], where Base station (BS) with multiple antennas (M) communicates with single user terminal having multiple antennas.
- Multi-user MIMO [3], where BS with multiple antennas communicates with multiple users (K) with single antennas.

In point-to-point MIMO, compact user terminal limits the number of antennas that can be installed in a compact user terminal. While MU-MIMO can have any number of spatially separated user terminals equipped with single antenna. Figure 1 shows a schematic illustration for MU-MIMO system.


(a)

(b)

Fig. 1 Illustration of the downlink and uplink transmission in a multi-user MIMO system, where the BS is equipped with *M* antennas and serves *K* user terminals simultaneously. This illustration focuses on line-of-sight propagation where the downlink signals can be viewed as angular beams, but multi-user MIMO works equally well in non-line-of-sight conditions. **(a)** Downlink in multi-user MIMO. **(b)** Uplink in multi-user MIMO

In the downlink, the BS multiplexes one data stream per user while in the uplink, receives one stream per user. BS uses its antennas to focus each signal towards its desired receiver and separates multiple signals received from multi-user, maximum number of data streams that can be transmitted simultaneously in a cell separable in spatial domain is given as min (M,K) and this is referred as multiplexing gain of MU-MIMO system.

B. *Massive MIMO*

Massive MIMO technique is based on equipping base stations (BSs) with hundreds or thousands of antennas. This can provide unprecedented array gains and allows multiple user MIMO communication to tens or hundreds of user equipments per cell. With massive MIMO things that were random before starts to look deterministic as a result the effect of small scale fading can be averaged out. Another advantage of massive MIMO, that it enables us to reduce transmitted power. On the uplink, reduction in transmit power results in more battery backup. Whereas on the downlink, reduction in emitted RF power results in low consumption of electricity.

In this paper, we provide some basic guidelines for designing of Massive MIMO network and showcase the SEs that the technology can deliver to 5G networks. We analyze the SE expressions valid for both uplink (UL) and downlink (DL) transmission with random user location and power control that yields uniform user equipment (UE) performance. We consider conventional linear processing schemes maximum ratio (MR) combining/ transmission and zero forcing (ZF) to suppress inter cell interference.

II. SYSTEM MODEL

Consider the system model were payload data is transmitted with universal time and frequency reuse. We consider multi-cell massive MIMO with *L* cells. Each cell consist of *M* antennas at the base station, single antenna user equipment at the time out of K_{max} user equipments. The subset of active user equipments changes over time, thus the name UE $k \in \{1,................, K\}$ in the cell $l \in L$ is given to different UE's at the different times. The geographical position $z_{lk} \in \mathbb{R}^2$ of UE *k* in cell l is therefore an ergodic random variable with cell specific distribution. The model is used to study the average performance of random interfering user equipments. The time and frequency resources are divided into frames of duration T_c seconds and W_c Hz, as shown in figure 1. Assuming frame dimensions such that T_c is less than or equal to coherence time of all UEs and W_c is less than or equal to coherence bandwidth for all user equipments which results all channels static within the frame: $h_{jlk} \in \mathbb{C}^N$ denotes the channel response between BS *j* and UE *k* in cell l. These channel responses are drawn as realisations from zero mean circular symmetric Complex Gaussian distributions:

$$h_{jlk} \sim CN\left(0, \beta_{l,k}^{l} I_M\right), \qquad (2)$$

where I_M is the $M \times M$ identity matrix. This is a theoretical model for non Line of Sight propagation [2]. Function $\beta_{l,k}^{l}$ gives the variation of the channel attenuation from BS j to any UE position *z*. The value of $\beta_{l,k}^{l}$ very slowly over time and frequency, thus we assume that it is known at the BS *j* for all l and *K* and that each UE knows its value to its serving BS.

We consider the time division duplex protocol, as shown in figure 2, where $B \geq 1$ out of *S* symbols in each frame are reserved for UL pilot signalling. Due to the channel reciprocity in time division duplex system there is no DL pilot signalling and no feedback CSI. The remaining $S-B$ symbols are allocated for payload data and are split between UL and DL transmission. Let $\zeta^{(ul)}$ and $\zeta^{(dl)}$ denote the fixed fractions allocated for UL and DL, respectively. These fractions can be selected arbitrary, subject to the constraint $\zeta^{(ul)} + \zeta^{(dl)} = 1$ and that $\zeta^{(ul)}(S-B)$ and $\zeta^{(dl)}(S-B)$ are positive integers.

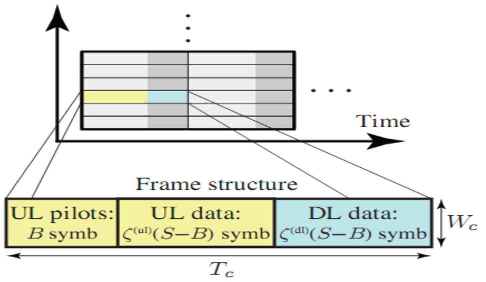


Fig. 2: The transmission is divided into frames of $S = T_c W_c$ symbols, whereof B symbols are dedicated to pilot transmission. The remaining $S-B$ symbols are used for payload data, where $\zeta^{(ul)}$ and $\zeta^{(dl)}$ are respectively the fractions of UL and DL transmission.

A. *Uplink*

The received UL signal $y_j \in \mathbb{C}^M$ at BS *j* in a frame is modelled similar to [3], as

$$y_j = \sum_{l \in L} \sum_{k=1}^{K} \sqrt{p_{lk}} h_{jlk} x_{lk} + n_j \tag{3}$$

Where $x_{lk} \in \mathbb{C}$ is the transmitted symbol by UE *k* in cell *l*. This signal is normalized as $E\{|x_{lk}|^2\} = 1$, while the corresponding UL transmit power is defined by $p_{lk} \geq 0$. The additive noise is modeled as $n_j \sim CN(0, \sigma^2 I_M)$, where σ^2 is the noise variance.

B. *Downlink*

The received DL signal $z_{jk} \in \mathbb{C}^M$ at UE *k* in cell *j* in a frame is modelled [3] as

$$z_{jk} = \sum_{l \in L} \sum_{m=1}^{K} h_{ljk}^{T} w_{lm} s_{lm} + n_{jk} \tag{4}$$

Where $(.)^T$ denotes transpose, s_{lm} is the symbol transmitted for UE *k* in the cell *l*, w_{lm} is the corresponding precoding vector. The additive noise is modeled as $n_{jk} \sim CN(0, \sigma^2)$, with same variance as the UL.

III. DESIGN GUIDELINES

We provide basic design guidelines for Massive MIMO which can deliver to 5G networks. We consider cellular network topology with hexagonal cells, where each cell looks as shown in figure1. BS is placed in the centre of each cell and users are distributed over the cell randomly. When many such cells are placed together, cellular network has the shape as figure 3.

A. *Power Allcation*

We assume a power allocation policy

$$p_{l,k} = \frac{\delta}{\beta_{l,k}^{l}} \quad l = 1,.....L \;\; k = 1,.......K \tag{5}$$

Where $\delta \geq 0$ is a design parameter. $p_{l,k}\beta_{l,k}^{l}$ determines average received signal power per antenna. Thus $\frac{p_{l,k}\beta_{l,k}^{l}}{\sigma_{BS}^{2}} = \frac{\delta}{\sigma_{BS}^{2}}$ determines the SNR achieved at each BS. This policy is called channel inversion power allocation.

B. *Non-Universal pilot allocation*

SE of a particular cell j is influenced by the pilot signaling carried in other cells. Degradation in channel state information (CSI) estimation increases due to interfering cells using same pilot sequence as cell j. Channel attenuation of the interference increases with distance which suggests placing interfering cells far away from cell j. We assume pilot reuse factor $f = \frac{\tau_p}{K}$ to be an integer, where τ_p is the pilot sequence length. This results division of L cells into group of *f* disjoints cells. Then, $f = 1$ is called as universal pilot reuse while $f > 1$ is called non-universal pilot reuse.

Fig. 3 illustrate such reuse pattern. Different colours use different sub sets of pilot sequences. Same coloured cells use exactly the same pilot sequence and results in pilot contamination to each other and not to cells of different colour.

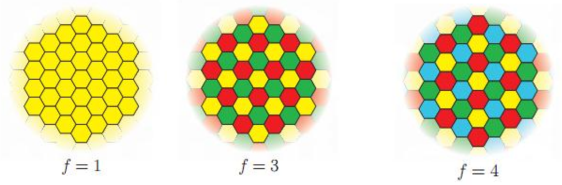
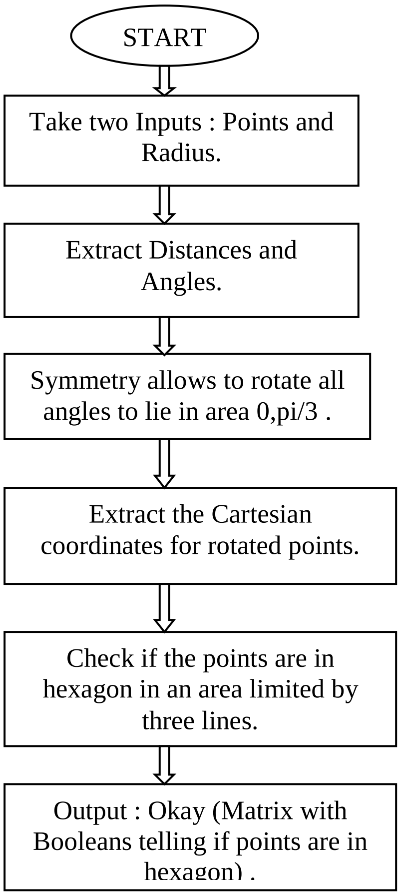


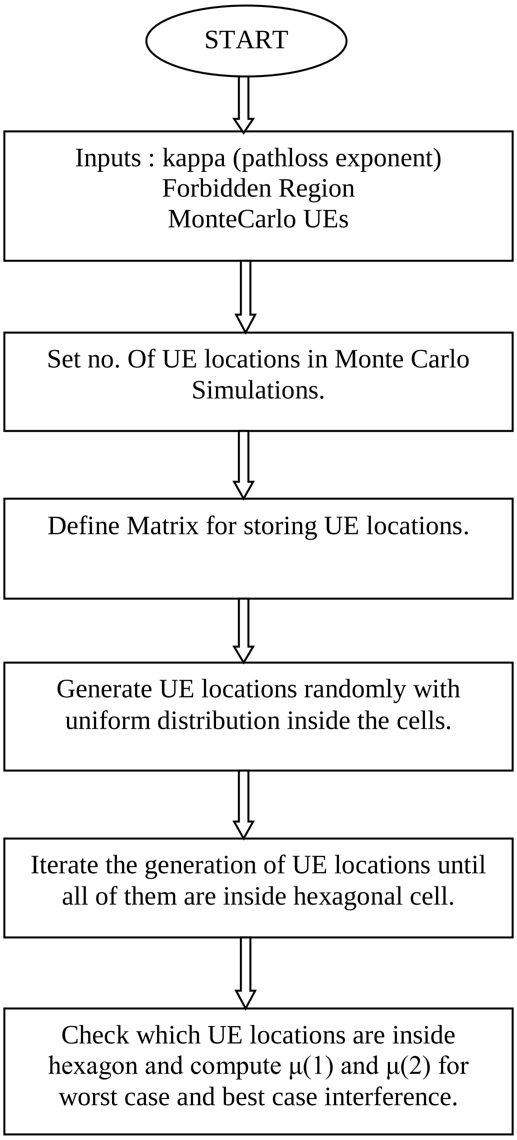
Fig 3. Illustration of potential symmetric reuse patterns created by three different pilot reuse factors, f, in a cellular network with hexagonal cells.

IV. FLOWCHARTS

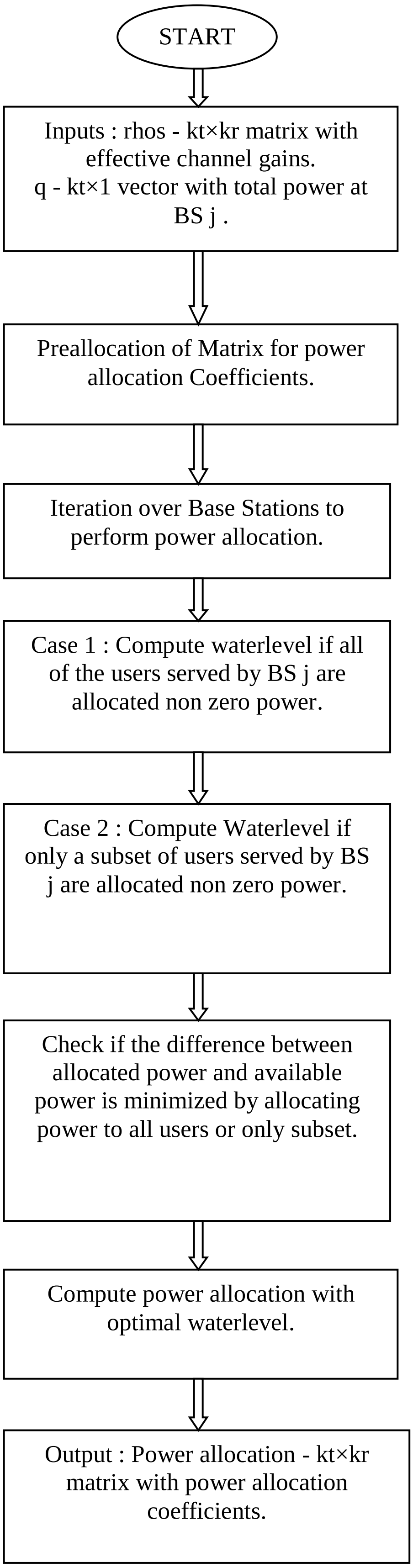
Flowchart for generating hexagonal network:



Flowchart for generating UE Locations



Flowchart for solving problem of uneven signal strength to users



V. SIMULATION RESULTS

We considered single cell scenario and linear precoding schemes such as (a) maximum ratio (MR) and (b) zero-forcing (ZF) to investigate how large gains can be achieved. Simulations are performed on MATLAB with $K = 10$ user terminals served simultaneously by a BS with M antennas. For simplicity, average SNR per user is assumed as 5 dB with perfect CSI available everywhere and channels are modelled as uncorrelated Rayleigh fading.

Fig. 4 shows that the multiplexing gain $\min(M, K)$ is outperforming when we consider $M > K$ as capacity increases with linear ZF processing and reaches upper curve, which represents bound when interference is neglected. So Massive MIMO with linear process such as ZF can serve all the K users as if each user is alone in the cell.

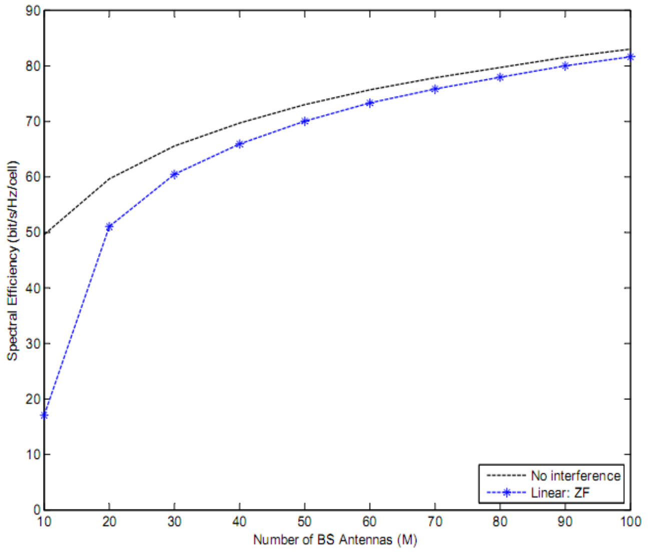


Fig 4. Average spectral efficiency in a multi-user MIMO system with K = 10 users and varying number of BS antennas. Each user has an average SNR of 5dB and the channels are Rayleigh fading.

Fig. 5 compares SE obtained for perfect CSI and CSI estimated with pilot signal with τ_p. Simulation results obtained represents SE as function of M and compares Time Division Duplexing (TDD) mode $\tau_p = K = 10$ with Frequency Division Duplexing (FDD) mode with $\tau_p = 10, \tau_p = M$ or $\tau_p = \min(M, 50)$. Result indicates that the performance loss for ZF precoding to MR precoding is more when compared to MR. TDD system benefits on adding more antennas while FDD system benefits on adding more antennas only if the pilot sequences are made longer.

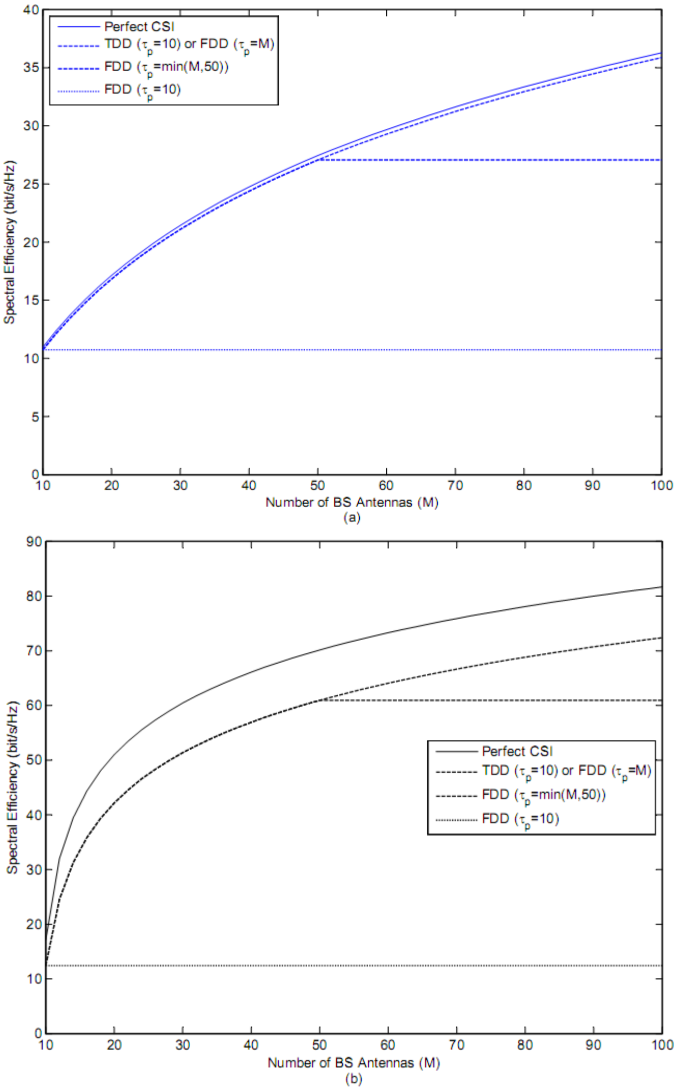
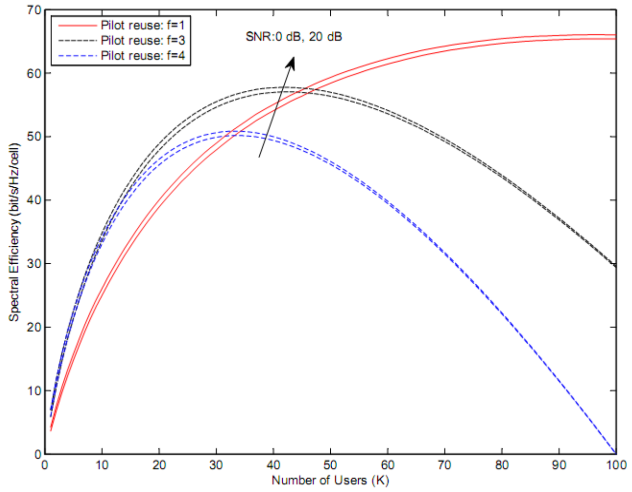
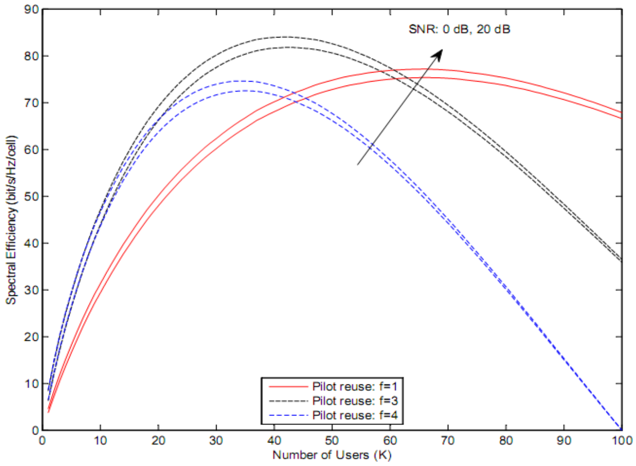


Fig 5. Average downlink spectral efficiency, as a function of the number of BS antennas, with different processing schemes and different types of CSI available at the BS. (a)Downlink simulation with maximum ratio precoding. (b) Downlink simulation with zero-forcing precoding.

Fig. 6 shows the average SE for different number of users in a multi-cell scenario. Simulation result indicates same performance for two SNR levels $\frac{\delta}{\sigma_{BS}^2} = 0$ dB and $\frac{\delta}{\sigma_{BS}^2} = 20$ dB. Array gains of Massive MIMO makes SE interference limited and not noise limited, hence it works equally for high and low SNR's. Result also indicates different pilot reuse factors at different user load. Moreover, difference in SE for ZF and MR is relatively small.



(a) Maximum Ratio Detection



(b) Zero Forcing Detection

Fig 6 Average spectral efficiency, as a function of the number of users, with different processing schemes and pilot reuse factors. Two different SNR levels are considered.

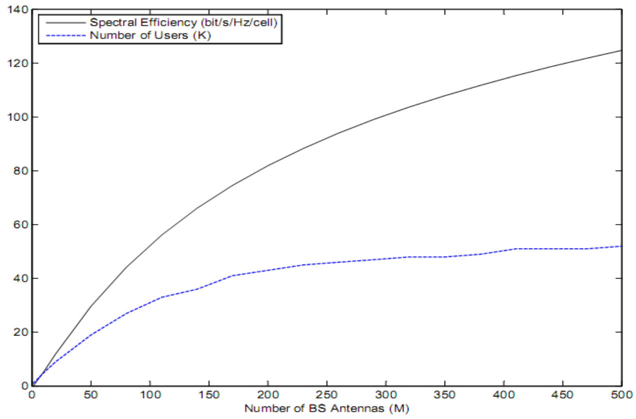


Fig 7. Average spectral efficiency, as a function of the number of BS antennas, with ZF processing, a pilot reuse factor f =3, and an SNR of 0 dB. The number of users is optimized for each antenna number to yield the highest SE, and the corresponding number of users is also shown.

Fig. 7 show optimization of number of active user for each M to achieve highest SE. The Massive MIMO network considered, achieves 52 bit/s/Hz/cell for M=100 antennas and 114 bit/s/Hz/cell for M=400 antennas. On dividing upper curve with bottom curve, we get SE per user which lies in the modest range of 1 to 2.5 bit/s/Hz. Such SE's can be achieved easily by using conventional modulations such as 16-QAM.

VI. CONCLUSION

Linear processing such as ZF or MR provides sum spectral efficiency close to upper bound where interference is neglected between users when $M \gg K$. Massive MIMO FDD systems are feasible with large antennas for slowly varying channels but it requires large pilot overhead. TDD systems are more scalable as pilot sequences only need to be of length K irrespective to M. High array gain makes Massive MIMO interference limited system and not noise limited. It performances equally well for high as well as low SNR's. Pilot reuse factor is an important design parameter whose choices depend on user load, environment and number of BS antennas.

REFERENCES

[1] Ericsson Mobility Report-Mobile World CONGRESS Edition-Feb 2016.
[2] An Overview of MASSIVE MIMO :Benefits and Challenges.(LU LU,Geoffrey Ye Li,A.Lee Swindlehurst)
[3] Massive MIMO for Spectral Efficiency:How Many Users and Pilots Should be Allocated? (Emil Bjornson, Erik G. Larsson, Merouane Debbah)
[4] X.Gao, O.Edfors, F.Rusek, and F.Tufvesson,"Massive MIMO performance evaluation based on measured propagation data,"IEEE.Trans.Wireless