Cell Free Massive MIMO vs User Centric Massive MIMO

MTP Phase-1: Report

Master in Technology

Submitted by

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Nomenclature

AP	Access Point
BS	Base Station
CF	Cell Free
CPU	Central Processing Unit
CSI	Channel State Information
DL	Downlink
$MIMO$	Multiple Input Multiple Output
MS	Mobile Station
PM	Pilot Matched
RV	Random Variable
$S-LMMSE$	Scalar-Linear Minimum Mean Square Estimate
UC	User Centric
$V-LMMSE$	Vector-Linear Minimum Mean Square Estimate

Abstract

This report mentions the downlink data transmission part for the User-Centric MM systems, large number of access points at once are disseminated randomly in an area to serve small number of users. Different channel estimation techniques have been used where with help of training phase that is using the uplink pilot transmisson, we obtain the channel estimates which would then be useful to transmit data from access points(APs) to the users on performing conjugate beamforming towards the desired user. We then compare the UC MM approach to the CF MM approach assuming that every single access point(AP) doesn't serve all the users inside the framework, rather just the ones that have the high channel gains.

Chapter 1

Introduction

Massive MIMO is a base of the reliable 5G technology where base stations(BSs) with multiple antennas provides services to different users on the identical time frequency resource. With lucid signal processing, with the use of this technology, high throughput and energy efficiency can be achieved [1],[2]. In Massive MIMO, an array of antennas are placed at wireless basestations(BSs) [3]. Recently, a modern technology named as CF MM has been introduced in [4],[5].it depicts, at first, uplink pilots are transmitted with the help of which every single access points obtains the channel estimate in the training phase and then performs conjugate beamforming for sending information to the users. In CF approach, access points are connected to a central processing unit through a backhaul network. The data which is to be transmitted to the mobile stations are sent to the access points first and in return estimates of the received data are obtained from all the access points. A point to note here is Obtained channel estimates as well as beamforming vectors , none of them are directed through the backhaul network.

A comparison has been made between user-centric technique and cell-free technique, where every MS is serviced by a chosen APs. The user-centric scheme takes less backhaul overhead compared to cell-free scheme and provide better results thatn the cell-free technique in aspect of per-user rate for majority of the users in the framework. Basic idea behind user-centric(UC) approach is that each access point doesn't serve every single user in the network, rather just the chosen one that have the high channel gain.

Different channel estimation techniques have been analysed with respect to both user-centric(UC) as well as cell-free(CF) approach.Later,it is easily seen from [6] that Since access points delivers signals to the users having strongest channel gains, In the cell-free case, number of bits travelling over the backhaul network considering the complete coherence time is more than that for the user-centric(UC) case. For a comparison, their is 83% less backhaul overhead in case of user-centric(UC)approach in comparison to cell-free(CF) approach.Also,the loss beared in the user-centric(UC) approach is about 11% for the for the users getting user-rate likely to be 95% but when it comes to getting user-rate likely to be 90% for the users,the user-centric method outperflanks the cell-free method by 4% and in terms of median-rate by 21%.

1.1 Problem Formulation

Comparing to the small cells massive MM technique, In terms of users getting user-rate likely to be 95%, CF MM gives superior execution but in cell-free approach, all access points employments time-division duplex(TDD) operation, coordinate in phase through a backhaul network, where every user is served within the same time-frequency asset and hence causing a huge backhaul overhead. So A modern architecture has been presented that is user-centric massive MM which would require less backhaul overhead as well as give more throughput in comparison to the cell-free approach and this could be accomplished in such a way that All access points serve specific mobile stations with strongest channel.

Chapter 2

SYSTEM MODEL

An area with P mobile stations and Q access points have been considered. Mobile stations and Access points are arbitrarily found within the area and available with only one antenna in it. The backhaul arrangement interfaces Q access points to a central processing unit where decryption of data takes place. From [4] and [5], all transmissions take place on the same frequency band; Time division duplex isolates uplink transmission and downlink transmission; the coherence interval is thus bifurcated into three stages of the process: (a)Uplink pilots are transmitted and with the help of which channel gain are estimated at the access points for every single user (b)transmission of data on the downlink side to the mobile station, and (c)data transmission on the uplink side from the mobile station to the access points. Our Focus will be more on the uplink pilot transmission stage and the downlink data transmission in this report. firstly, the mobile stations send pilot matrix to the access points, so that channel could be estimated at the access point side. Secondly, Access points obtains the estimate of the channel and does channel matched beamforming by taking the product of the estimate of channel and the data symbol that is supposed to be transmitted and finally, transmits data on the downlink; whereas within the CF MM system, access points transmits data to every mobile station in the system, while in the user centric approach, access points sends data only to chosen mobile stations in the system. Finally, mobile stations transmits uplink data symbols to the access points; whereas within the cell-free architecture all the access points appears its involvement to the decryption of the information transmitted by all the mobile staions, in the user centric method access points just decrypts the information from the mobile stations they receive best signal or in other words, particular users with highest channel gain. A point to note here is that pilot transmission is not necessary at the mobile station side and also the calculation of the estimate of the channel is also not necessary at the mobile stations side.

2.1 Channel Model

The same channel model has been utilized as in [4] and [5]. $c_{p,q}$ indicates the channel between the p-th mobile station and the q'-th access point. $c_{p,q} = \beta_{p,q}^{1/2} s_{p,q}$, where $\beta_{p,q}$ is a scalar coefficient which models the path-loss in the channel and takes under consider the shadowing effects too and $s_{p,q}$ is a $\mathcal{CN}(0,1)$ random variable which represents the small scale fading. $s_{p,q}$ are accepted to be statistically independent in reference to p and q. $\beta_{p,q}= 10^{\frac{\text{PathL}}{10}}\ 10^{\frac{\sigma_{\text{sd}} corr_{p,q}}{10}}$ (denoted in dB) is the large scale fading coefficient between the p -th mobile station and the q -th access point, and $10^{\frac{\sigma_{\text{sd}} corr_{p,q}}{10}}$ expresses the shadow fading with standard deviation σ_{sd}, whereas $corr_{p,q}$ will be presented little later. We take the reference of following three slope model for calculating the path loss [7] [8]:

$$\text{PathL}_{p,q} = \begin{cases} -fsl - 35\log_{10}\left(dis_{p,q}\right), & \text{if } dis_{p,q} > dis_1 \\ -fsl - 10\log_{10}\left(dis_1^{1.5} d_{p,q}^2\right), & \text{if } dis_0 < dis_{p,q} \leq dis_1 \\ -fsl - 10\log_{10}\left(dis_1^{1.5} dis_0^2\right), & \text{if } dis_{p,q} < dis_0 \end{cases} \tag{2.1}$$

where $dis_{p,q}$ indicates the separation between the q-th access point and the p-th user, fsl is

$$\begin{aligned} fsl =& 46.3 + 33.9\log_{10}(fsl) - 13.82\log_{10}\left(t_{\text{AP}}\right) \\ & - \left[1.11\log_{10}(freq) - 0.7\right] r_{\text{MS}} + 1.56\log_{10}(freq) - (0.8) \end{aligned} \tag{2.2}$$

where $freq$ represnts the frequency of carrier in MHz, t_{AP} & r_{MS} indicates the access point & heights of mobile stations and antenna, respectively. In practical environment,nearby transmitters & receivers may be encompassed by same impediments, this way, the shadow fading random variables are correlated[9]. Here, the two-components model has been utilized $corr_{p,q} = \sqrt{\delta} aa_q + \sqrt{1-\delta} bb_p, \quad q = 1, \ldots, Q, \quad p = 1, \ldots, P$, where aa_q is normal distributed with zero mean and unit variance and bb_p is also normal distributed with zero mean and unit variance and are independent RVs, and δ, where δ, lies between zero and one is a parameter. The covariance functions of aa_q and bb_p are given by:

$$Expec\left[aa_q aa_{q'}\right] = 2^{-\frac{dis_{\text{AP}}(q,q')}{\text{decorrdis}}} \quad Expec\left[bb_p bb_{p'}\right] = 2^{-\frac{dis_{\text{MS}}(p,p')}{\text{decorrdis}}} \tag{2.3}$$

where $dis_{\text{AP}}\left(q, q'\right)$ is the separation between the q-th and $q'-$ th access points $dis_{\text{MS}}\left(p, p'\right)$ is the separation between the p-th and the p'-th mobile stations.

Chapter 3

THE COMMUNICATION PROCESS

A. Uplink Training

T_c denotes the length of the channel coherence time in samples, and T_{pi} denotes the length of the uplink training pilots. This condition must be obeyed, $T_{pi} < T_c$. Denote by ϕ_p the T_{pi} -dimensional column pilot sequence transmitted by the p -th MS, and consider that $\|\phi_p\|^2 = 1$. The signal obtained at the q -th access point during the training phase can be expressed through the following T_{pi} -dimensional column vector:

$$\mathbf{r}_q = \sum_{p=1}^{P} \sqrt{roh_p} c_{p,q} \phi_p + \mathbf{n}_q \tag{3.1}$$

with roh_p denoting the power transmitted by the p -th user during the training phase, and $\mathbf{n}_q$ a T_{pi} -dimensional vector containing the contribution of noise and out-of-cell interference at the q -th access point; its entries are assumed to be i.i.d. $\mathcal{CN}\left(0, \sigma_n^2\right)$ random variables. Based on the received vector r_q, and using the pilot sequences, estimate of the channel coefficients are obtained by the q -th access point. $\{c_{p,q}\}_{p=1}^{P}$. We assume here knowledge of the mobile stations transmit powers $\{roh_p\}_{p=1}^{P}$, and look forward to three different channel estimation strategies:

1) Pilot-Matched (PM) Channel Estimation: The estimate, $\widehat{c}_{p,q}$ say, of the channel coefficient $c_{p,q}$ is formed as $\widehat{c}_{p,q} = \frac{1}{\sqrt{roh_p}} \phi_p^H \mathbf{r}_q$, with $(\cdot)^H$ denoting conjugate transpose.

2) Scalar Linear Minimum Mean Square Error (S-LMMSE) Channel Estimation: considering the fact we know the shadowing coefficients $\beta_{p,q}$, as in [5] [10] [11], we form an LMMSE estimate of $c_{p,q}$ based on the statistics $\phi_p^H \mathbf{r}_q$, as:

$$\widehat{c}_{p,q} = \frac{\sqrt{roh_p} \beta_{p,q} \phi_p^H \mathbf{r}_q}{\sum_{i=1}^{P} roh_i \beta_{i,q} \left|\phi_p^H \phi_i\right|^2 + \sigma_n^2} \tag{3.2}$$

B. Downlink Data Transmission

The access points considers the channel estimates as if they are the true channels, and performs conjugate beamforming on the downlink side and thus, each mobile station receives phase-aligned contributions from the access points and on its side does not need to perform channel estimation.

1) UC Massive MIMO Architecture: In the user centric approach, we assume that the access points connects only with the mobile stations having high channel gains. In particular, the q -th access point, after obtaining the estimates $\widehat{c}_{p,q}, \forall p=1,\ldots,P$, sorts these estimates in decreasing order and transmits only to the num mobile stations with the channel having largest norm, with num being a proper design parameter. [1] We denote by $\mathcal{P}(q)$ the set of mobile stations serviced by the q -th access point. Given the sets $\mathcal{P}(q)$, for all $q=1,\ldots,Q$, we define a set $\mathcal{Q}(p)$ of the access points that connects with the p -th user as $\mathcal{Q}(p)=\{q : p \in \mathcal{P}(q)\}$. So, in this case, the signal transmitted by the q -th access point in the n -th interval is given by:

$$sym_q(n) = \sum_{p \in \mathcal{X}(q)} \sqrt{\eta_{p,q}^{\mathrm{DL}}} \hat{c}_{p,q}^{*} x_p^{\mathrm{DL}}(n) \tag{3.3}$$

with $x_p^{\mathrm{DL}}(n)$ the downlink data-symbol, and $\eta_{p,q}^{\mathrm{DL}}$ a scalar coefficient which controls the power transmitted by the q -th access point.Assuming roh_q^{DL} denote the transmitted power by the q -th access point, we let $\eta_{p,q}^{\mathrm{DL}} = \frac{roh_q^{\mathrm{DL}}}{\sum_{\ell \in X(q)} |\widehat{c}_{\ell,q}|^2}$. The power ia allocated such that the q -th AP, based on $\widehat{c}_{p,q}$, with $k \in \mathcal{P}(q)$, divides its power roh_q^{DL} in a way that is proportional to the estimated channel strengths. Else, the power utilized by the q -th access point to transmit to the p -th mobile station is $\frac{roh_q^{\mathrm{DL}} |\hat{c}_{p,q}|^2}{\sum_{\ell=1}^{P} |\widehat{c}_{\ell,q}|^2}$ Thus, users with good channel will receive a larger part of the transmitted power and users with bad channels will be ignored; this power control rule is inspired by the maximum ratio combining rule for multipath diversity reception. In general, p -th mobile station receives contributions from all the access points; the received estimate for the data symbol $x_p^{\mathrm{DL}}(n)$ is thus:

$$\hat{x}_p^{\mathrm{DL}}(n) = \sum_{q=1}^{P} c_{p,q} sym_q(n) + z_p(n) \tag{3.4}$$

with $z_p(n)$ the $\mathcal{CN}\left(0, \sigma_z^2\right)$ additive noise. Using (3.3) and (3.4), desired calculations lead to the definition of the downlink Signal to the interference ratio(which includes noise component in addition to the side components which would be treated as noise as well)ie in short SINR(signal to noise interference ratio) for the p -th mobile station[12]:

$$\gamma_p^{\mathrm{DL}} = \frac{\left| \sum_{q \in \mathcal{P}(p)} \sqrt{\eta_{p,q}^{\mathrm{DL}}} c_{p,q} \widehat{c}_{p,q}^{*} \right|^2}{\sigma_z^2 + \sum_{i=1, i \neq p}^{P} \left| \sum_{q \in \mathcal{P}(i)} \sqrt{\eta_{i,q}^{\mathrm{DL}}} c_{p,q} \widehat{c}_{i,q}^{*} \right|^2} \tag{3.5}$$

The downlink rate for the p -th mobile station, assuming Gaussian data-symbols, is expressed as $\mathcal{R}_p^{\mathrm{DL}} = BW \log_2(1+\ \gamma_p^{\mathrm{DL}})$, with BW the communication bandwidth.

2) CF Massive MIMO Architecture: The CF approach can be obtained as a special case of the UC approach by putting $num = P$, i.e., $\mathcal{P}(q) = \{1, \ldots, P\}, \forall q$

Chapter 4

PERFORMANCE ANALYSIS AND RESULTS

The user-centric approach provides saving in terms of required backhaul capacity. Amid downlink transmission, within the cell-free approach the CPU sends, for every symbol interval, Q times the P data symbols, i.e., the overhead per symbol interval is equal to the product QP; this decrease to $Qnum$ within the user-centric case since the CPU just sends, to the Q access points, only num data symbols. During the uplink transmission part, for the cell-free approach, information gets decoded by every access point from all the users and is sent to the CPU, in each symbol interval: QP transmissions of complex coefficients are required. Within the user-centric case, every access point decodes information from num mobile stations only, and, hence, there's a necessity of MN transmissions of complex coefficients. We too ought to take under consideration the overhead required by the mobile station(MS) selection stage within the user-centric case: in general, based on the assessment of the channel gain, each access point chooses the N mobile stations it'll service and send this choice to the central processing unit(CPU). since $\lceil \log_2 P \rceil$ bits are required to identify each user within the network, [2] this requires that each access point sends $num \lceil \log_2 P \rceil$ bits, i.e., a total on $numQ \lceil \log_2 P \rceil$ bits are to be sent on the backhaul network. In each channel coherence time,transmission is done i.e.,based on time that's much bigger than the symbol interval. For a normal framework with $Q = 100$ access points,$P = 30$MSs, $num = 5$ served mobile stations within the user-centric approach, assuming that the channel coherence time ranges $Len = 1000$ symbol intervals, which means 64 bits are required, and considering QPSK modulation (2 bits per data symbol), it is easily deduced that within the cell-free case the number of bits voyaging on the backhaul over the total coherence time is $(2QP+64QP)Len = 1.98 \cdot 10^8$, while for the user-centric case we have $numQ \lceil \log_2 P \rceil + (2Qnum + 64Qnum)Len = 3.3 \cdot 10^7$ i.e., Overhead is 83% less in comparison to cf massive MIMO.

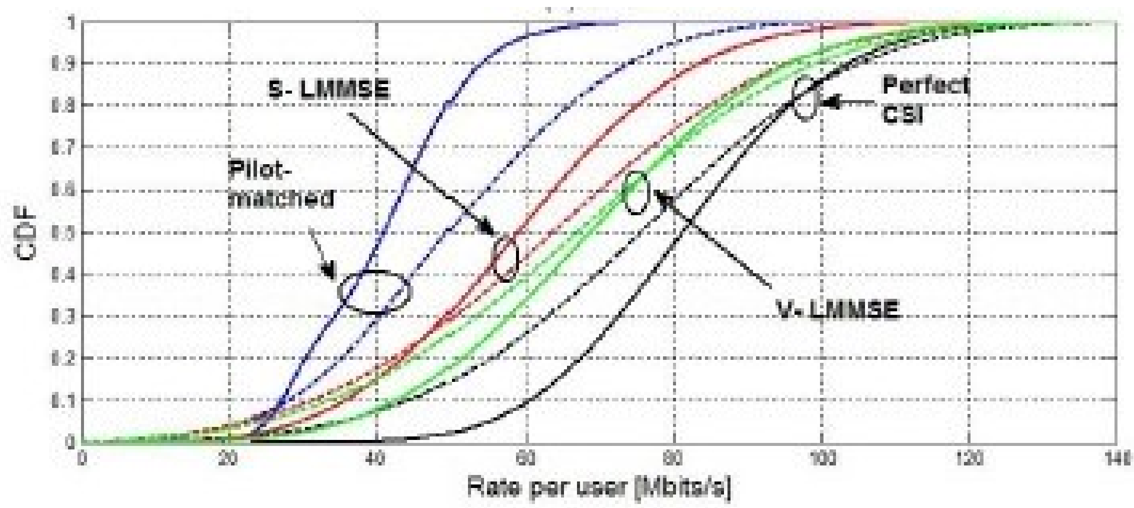

Figure 4.1: cummulative distribution function plot for per user rate vs cdf. In user-centric case, we have num=2 and for the cell-free case, num=P.

let us induce essentially from the gotten numerical comes about, which can show the rate obtained by every single user, calculated in Megabit/s. Our expository calculation setup matches with the one in [4] and [5]; we consider a numerical value of communication bandwidth as $BW =$ 20MHz centered over the frequency of carrier $freq_0 = 1.9$GHz. The height of access points we have assumed is 15m and that for the height of mobile stations is 1.65m. The standard deviation of the shadow fading we have considered is $\sigma_{\rm sd} = 8$dB, the parameters for the three slope path loss model in (2.1) are also have been referred for calculation of the rate achieved by every single user $dis_1 = 50$m and $dis_0 = 10$m, the parameter δ we assume as 0.5 & the noise figure taken for the calulation is 9 dB. We consider a square area where we distribute the access points for serving the users of 1km^2 with $Q = 100$ access points. It is assumed that pilot sequences are binary and orthogonal so that every user can be uniquely identified and there won't be any effect of pilot contamination, and of length $_{pi} = P$, length of the pilots is considered. The uplink transmitted power during both training phase and data transmission is 100mW, for all mobile stations, while the downlink transmit power is 200mW.

Fig 4.1 from [6] , it shows the cummulative distribution function of the per user rate for the uplink tranmission & downlink transmission, respectively, and for a low-user-density, ($P = 10$) situation, comparison between cell-free case(solid dash line) and UC(dotted line) has been made, wherein each access point serves the num users with the best channels. The choice $num = 2$ is for the case where the density of the user is low. Some important observations are also taken as follows. With culminate CSI(channel state Informatin), the cell-free approach continuously outflanks the user-centric approach; in any case, we push upon the truth that the user-centric approach has lower complexity. With less complex estimation schemes, instep, it is watched that the user-centric approach beats the cell-free one, in terms of normal data rate per user, with 30%+ margin. [3] With respect to the cummulative distribution function, the cell-free approach gives in many cases marginally way better execution than the user-centric approach to few users with bad channel gain, though the user-centric approach to a great extent outflanks the cell-free approach for the majority of users.Note that the cumulative distribution function) curves corresponding to the UC approach and to the cell-free approach have intersection points; since the ordinate of the intersection point for PM channel estimation remains well underneath 0.5, it appears that for the majority of the users the user-centric approach beats the cell-free approach. Moreover, From Fig. 4.1, it could be noticed that for the case $P = 10$ with PM(Pilot-matched) channel estimation, the users in downlink getting user-rate likely to be 95% is 22.34 (25.2) Mbit/s for the user-centric(cell-free) approach, i.e., the misfortune of information rate of the user-centric approach is around 11%; whereas the user-centric approach beats the cell-free approach by 4% in terms of users getting user-rate likely to be 90%, and in terms of median-rate by 21% .

Chapter 5

FUTURE WORK

This report compares the CF Massive MIMO system with the UC Massive MIMO system where every single access point only decrypts a pre-allocated mobile stations for different channel estimation techniques such as Pilot matched, Scalar LMMSE, Perfect channel estimation. It can be observed that with simple channel estimation methods, the User-Centric approach outflanks the Cell-Free one, except for few users having bad channel or low channel gain. The future work will be focused on the simulation based result for all of the channel estimation techniques that are mentioned above.These would be performed for the high density users as well along with the uplink of UC Massive MIMO to infer more important results.

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