Access Detection

***Abstract*—**

***Index Terms*—Massive MIMO, Cell-free,**

I. Introduction

A. *Related work*

B. *Motivations and Contributions*

In the process of following several studies on Cell-Free Massive MIMO systems, we found that all SINR calculation results indicate that connecting to all APs in a Cell-free system Massive MIMO does not necessarily bring a good performance. On the other hand, it is very difficult to find out which connection method gives the highest performance and can only use Brute force algorithm. Therefore, this study is written to provide a way to find a connection state that is good enough compared to Fully Connected, but the computational complexity of the proposed algorithm must also be good enough when compared with Brute's algorithm. force. The main contributions of this study include:

- We present an algorithm to find the connection state that can significantly improve the system performance compared to the Fully connected method based on checking the connection condition of each user with each AP.
- Provide an algorithm that includes the order and conditions of each user's connection check with each AP, thereby saving a lot of time compared to finding the connection status by Brute force.

$Notation$: Lower boldface letters denote column vectors. The superscript $(\cdot)^*$, $(\cdot)^T$, $(\cdot)^H$ stands for the conjugate, transpose, and conjugate-transpose operator, respectively. The Euclidean norm and the expectation operators are denoted by $\|\cdot\|$ and $\mathbb{E}\{.\}$ respectively. $[a\,b]$ is denoted the join of 2 matrices in the column direction. $\lceil\cdot\rceil$ is the ceiling function. Finally, $\mathcal{CN}\left(0,\sigma^2\right)$ denotes a circularly symmetric complex Gaussian distribution with zero mean and variance σ^2 and $\mathcal{N}\left(0,\sigma^2\right)$ denotes a Gaussian distribution.

II. System Model

Motivated by [1], [2], we consider a CF-massive MIMO system consisting of single- antenna K UEs and M Access Points (APs), each equipped with N antenna, and satisfy the condition $MN \gg K$. As usual, we consider the system operating in TDD mode with the first pilot phase to estimate the channel and then use this CSI to data transmission phase. In uplink training phase, the users send pilot sequence to the APs and each AP estimates channel to all users. The obtained channel estimation is used to precode downlink transmit signal and detect uplink signal. To avoid sharing channel state information (CSI) between the APs, we consider conjugated beamforming in downlink and match filter in uplink.

Let $g_{mk} \in \mathbb{C}^N$ denote the vector response channel between multi-antenna m^{th} AP and k^{th} user. We assume that the channel is an independent Rayleigh fading channel, thereby $g_{mk} \in \mathcal{CN}\{0, \beta_{mk} I_N\}$, where β_{mk} is large-scale fading including path-loss and correlated shadowing.

In this paper, we will consider the case that a user will only connect to some APs but not all, this connection state is represented by the connection matrix A, where

$$\mathrm{A}_{mk} = \begin{cases} 1, \text{ if connected} \\ 0, \text{ if not connected} \end{cases}$$

A. *Uplink Training Phase*

Let τ_c denote length of each coherence interval. τ_u^{p} is length of uplink training phase ($\tau_u^{\mathrm{p}} < \tau_c$). During uplink phase, all users send their pilot sequences of length τ_u^{p} simultaneously to APs. $\sqrt{\tau^{\mathrm{p}_u}}\boldsymbol{\varphi}_k \in \mathbb{C}^{\tau^{\mathrm{p}_u}}$ where $\|\boldsymbol{\varphi}_k\|^2 = 1$ is pilot sequence used by k^{th} user. The received pilot vector in m^{th} AP is given as

$$Y_{p.m} = \sqrt{\tau_u^{\mathrm{p}} p_i^{\mathrm{CF}}} \sum_{k=1}^{K} g_{im} \varphi_i^H + \boldsymbol{W}_{p,m}, \tag{1}$$

where p_i^{CF} is normalized signal to interference ratio (SNR) of each pilot symbol. $W_{p,m}$ is AWGN of m^{th} user.

Based on received pilot signal, m^{th} AP estimates the channel $g_{mk} \in \mathbb{C}^{N\times K}$ with $k = [1, 2, \ldots, K]$. Let $\hat{y}_{p,mk}$ is projection of y_{mk} in $\boldsymbol{\varphi}_k^H$.

$$\begin{aligned} \hat{y}_{p,mk} &= \boldsymbol{\varphi}_k^H \boldsymbol{Y}_{p,m} \\ &= \sqrt{\tau^{\mathrm{p}_u} p_p^{\mathrm{CF}}} g_{mk} + \sqrt{\tau^{\mathrm{p}_u} p_p^{\mathrm{CF}}} \sum_{k' \neq k}^{K} g_{mk'} \boldsymbol{\varphi_{kk'}} \\ &+ \boldsymbol{\varphi}_k^H w_{p,m}, \quad \text{where} \quad \varphi_{kk'} \triangleq \varphi_K^H \varphi_{k'}. \end{aligned} \tag{2}$$

Although with random pilot sequences, $\hat{Y}_{p,mk}$ is still not sufficiently statistic for the estimation of g_{mk}, we can still use this quantity to obtain the suboptimal estimation, in special case, when 2 pilots is exactly same or orthogonal, then $\hat{y}_{p,mk}$ is sufficiently statistic, and the estimation based $\hat{y}_{p,mk}$ is optimal. MMSE estimate of g_{mk} is given by

$$\begin{aligned} \hat{g}_{mk} &\triangleq \mathbb{E}\{g_{mk}\hat{y}_{p,mk}^H\}\mathbb{E}\{\hat{y}_{p,mk}\hat{y}_{p,mk}^H\}^{-1}\hat{y}_{p,mk} \\ &= c_{mk}\hat{y}_{p,mk} \end{aligned} \tag{3}$$

where

$$c_{mk} \triangleq \frac{\sqrt{\tau^{\mathrm{p}_u} p_p^{\mathrm{CF}}}\beta_{mk}}{\tau^{\mathrm{p}_u} p_p^{\mathrm{CF}} \sum_{j=1}^{K} \beta_{mj} |\varphi_k^H \varphi_j| + 1}$$

The MMSE channel estimate is distributed as

$$\hat{g}_{mk} \backsim \mathbb{CN}\left(0, \gamma_{mk} I_N\right)$$

where

$$\gamma_{mk} = \sqrt{\tau^{\mathrm{p}_u} p_p^{\mathrm{CF}}} c_{mk}\beta_{mk} \tag{4}$$

Note that pilot contamination is shown in the term $\varphi_k^H \varphi_j$ and here this value is equal to 1. When two users share the same pilot sequence, it is possible to have the following relationship:

$$\hat{g}_{mk} = \frac{\beta_{mk}}{\beta_{mj}} \hat{g}_{mj} \tag{5}$$

$$\gamma_{mk} = \frac{\beta_{mk}}{\beta_{mj}} \gamma_{mj} \tag{6}$$

Finally, channel estimation error is given by:

$$\tilde{g}_{mk} = g_{mk} - \hat{g}_{mk}$$

which is distributed as

$$\tilde{g}_{mk} = \backsim \mathbb{CN}\left(0, \left(\beta_{mk} - \gamma_{mk}\right) I_N\right)$$

B. *Uplink Payload Data Transmission*

In uplink phase, all users simultaneously send its data to APs. Before sending data, k^{th} user weighted its symbol q_k, $\mathbb{E}\left\{\|q_k\|^2\right\} = 1$, by power control coefficient $\sqrt{\eta_k}, 0 \leq \sqrt{\eta_k} \leq 1$. Received signal in m^{th} AP is given as

$$y_{u,m} = \sqrt{p_u} \sum_{k=1}^{K} g_{mk} \sqrt{\eta_k} q_k + w_{u,k}, \tag{7}$$

where p_u is normalized SNR for uplink. $w_[u, m]$ represents AWGN.

To detect transmitted signal from user q_k, m^{th} AP multiplies received signal $y_{u,m}$ with conjugate (locally obtained) of channel estimate. Then the obtained quantity $A_{mk}\hat{g}_{mk}^* y_{u,m}$ is transmitted to CPU via back-haul network. The signal received at CPU is given as

$$\begin{aligned} r_{u,k} &= \sum_{m=1}^{K} A_{mk}\hat{g}_{mk}^* y_{u,m} \\ &= \sum_{k'=1}^{K}\sum_{m=1}^{M} A_{mk}\sqrt{p_u \eta_k}\hat{g}_{mk}^* g_{mk'} q_{k'} + \sum_{m=1}^{M} A_{mk}\hat{g}_{mk}^* w_{u,m}. \end{aligned} \tag{8}$$

III. Performance Analysis

A. *Uplink rate*

Consider cell-free Massive MIMO system has K single antenna users, M APs, each of them is equipped with N antennas. The recceived signal in m^{th} AP in uplink payload phase is given by:

$$\begin{aligned} r_{u,k} &= \sum_{m=1}^{K} A_{mk}\hat{g}_{mk}^* y_{u,m} \\ &= \sum_{k'=1}^{K}\sum_{m=1}^{M} A_{mk}\sqrt{p_u \eta_k}\hat{g}_{mk}^* g_{mk'} q_{k'} + \sum_{m=1}^{M} A_{mk}\hat{g}_{mk}^* w_{u,m}. \\ &= \sqrt{p_u \eta_k}\sum_{m=1}^{M} A_{mk}\mathbb{E}\{\hat{g}_{mk}^* g_{mk}\} x_k \\ &+ \left(\sqrt{p_u \eta_k}\sum_{m=1}^{M} A_{mk}\hat{g}_{mk}^* g_{mk} x_k - \sum_{m=1}^{M} A_{mk}\mathbb{E}\{\hat{g}_{mk}^* g_{mk}\} x_k\right) \\ &+ \sum_{k'\neq k}^{K}\sum_{m=1}^{M} A_{mk}\sqrt{p_u \eta_{k'}}\hat{g}_{mk}^* g_{mk'} x_{k'} + \sum_{m=1}^{M} A_{mk}\hat{g}_{mk}^* w_{u,m} \\ &= DS_k x_k + BU_k x_k + \sum_{k'\neq k}^{K} UI_{kk'} x_{k'} + \sum_{m=1}^{M} A_{mk}\hat{g}_{mk}^* w_{u,m} \end{aligned} \tag{9}$$

So, we have the SINR formula given by:

$$SINR_k = \frac{|DS_k|^2}{\mathbb{E}\{|BU_k|^2\} + \sum_{k'\neq k}^{K}\mathbb{E}\{|UI_{kk'}|^2\} + \sum_{m=1}^{M}\mathbb{E}\{|A_{mk}\hat{g}_{mk}^* w_{u,m}|^2\}} \tag{10}$$

From [1], we have

$$|DS_k|^2 = p_u \eta_k N^2 \left(\sum_{m=1}^{M} A_{mk}\gamma_{mk}\right)^2$$

$$\mathbb{E}\{|BU_k|^2\} = p_u N \sum_{k=1}^{K} \eta_k \sum_{m=1}^{M} A_{mk}\gamma_{mk}\beta_{mk}$$

$$\mathbb{E}\{|UI_k|\} = \sqrt{p_u} N \sum_{k'\neq k}^{K} \eta_{k'} \left(\sum_{m=1}^{M} A_{mk}\gamma_{mk'}\frac{\beta_{mk}}{\beta_{mk'}}\right) |\varphi_k^H \varphi_{k'}|$$

$$\mathbb{E}\{|A_{mk}\hat{g}_{mk}^* w_{u,m}|^2\} = N \sum_{m=1}^{M} A_{mk}\gamma_{mk}$$

So we have k^{th} user's SINR formula given in (11):
and uplink rate is given by:

$$R_k = log_2\left(1 + SINR_k\right) \tag{12}$$

To serve the calculation and use of the algorithms outlined in the following, we have the SINR formula and the uplink rate of k^{th} user at m^{th} AP given by (13) and (14):

$$r_{mk} = log_2\left(1 + SINR_{mk}\right) \tag{14}$$

$$SINR_k = \frac{p_u \eta_k N^2 \left(\sum_{m=1}^{M} A_{mk} \gamma_{mk} \right)^2}{p_u N \sum_{k=1}^{K} \eta_k \sum_{m=1}^{M} A_{mk} \gamma_{mk} \beta_{mk} + p_u N^2 \sum_{k' \neq k}^{K} \eta_{k'} \left(\sum_{m=1}^{M} A_{mk} \gamma_{mk'} \frac{\beta_{mk}}{\beta_{mk'}} \right)^2 |\varphi_k^H \varphi_{k'}|^2 + N \sum_{m=1}^{M} A_{mk} \gamma_{mk}} \tag{11}$$

$$SINR_{mk} = \frac{p_u \eta_k N^2 \left(\gamma_{mk} \right)^2}{p_u N \sum_{k=1}^{K} \eta_k A_{mk} \gamma_{mk} \beta_{mk} + p_u N^2 \sum_{k' \neq k}^{K} \eta_{k'} \left(A_{mk} \gamma_{mk'} \frac{\beta_{mk}}{\beta_{mk'}} \right)^2 |\varphi_k^H \varphi_{k'}|^2 + N \gamma_{mk}} \tag{13}$$

Lemma 1. *Assuming k^{th} user is connected to any m APs, R_k will increase if $(m+1)^{th}$ AP connected to k^{th} user satisfies the following condition :*

$$\gamma_{(m+1)k} \sum_{m=1}^{M} \gamma_{mk} > \frac{1}{2} \gamma_{(m+1)k}^2 \left(\frac{k_1}{k_2} - 1 \right) + 2 p_u N^2 \sum_{k' \neq k}^{K} \gamma_{(m+1)k} \frac{\beta_{(m+1)k'}}{\beta_{(m+1)k}} \sum_{m=1}^{M} A_{mk} \gamma_{mk'} \frac{\beta_{mk}}{\beta_{mk'}} |\varphi_k^H \varphi_{k'}| \tag{15}$$

where

- k_1 is SINR of m connected APs
- k_2 is single SINR of $(m+1)^{th}$ AP

B. Connecting condition

In a cell-free massive MIMO system, when a user connects to all APs, he will receive a significant amount of interference and noise while being able to receive only a relatively small desired signal at APs with poor channel gain. This will reduce the quality of the system significantly and can be seen at 11. Therefore, finding the connection matrix A will help improve the performance of the system significantly. Even so, the problem of finding matrix A with the highest efficiency is almost impossible to solve in a practical massive MIMO cell-free system due to its complexity when using Brute-force algorithm. Therefore, in this section, we provide a condition that allows to solve the problem in a near-optimal manner and with significantly lower mathematical complexity.

Even so, calculating the SINR directly also requires a relatively large computational complexity. Therefore, in this section, we will find a way to reduce the computational complexity for the connection condition check step.

First, we consider the connection conditional lemma (Lemma 1).

To prove Lemma 1, from (11), we can rewrite uplink SINR with power control coefficient $\eta_k = 1$ as follow:

$$SINR = \frac{X^2}{Y + \sum_{k' \neq k}^{K} Z^2}$$

where

$$X = \sqrt{p_u N^2} \sum_{m=1}^{M} A_{mk} \gamma_{mk}$$

$$Y = p_u N \sum_{k=1}^{K} \sum_{m=1}^{M} A_{mk} \gamma_{mk} \beta_{mk} + N \sum_{m=1}^{M} A_{mk} \gamma_{mk}$$

$$Z = \sqrt{p_u N^2} \sum_{m=1}^{M} A_{mk} \gamma_{mk'} \frac{\beta_{mk}}{\beta_{mk'}} |\varphi_k^H \varphi_{k'}|$$

So, we can show k_1 and k_2 respectively:

$$k_1 = \frac{X^2}{Y + \sum_{k' \neq k}^{K} Z^2}$$

$$k_2 = \frac{P^2}{Q + \sum_{k' \neq k}^{K} R^2}$$

Therefore, the user's SINR when connected to (m+1) APs can be represented as:

$$k = \frac{(X+P)^2}{Y + Q + \sum_{k' \neq k}^{K} (Z+R)^2}$$

In here we find the condition for $k > k_1$ or we can rewrite as follow:

$$\frac{(X+P)^2}{Y+Q+\sum_{k'\neq k}^{K}(Z+R)^2} > k_1$$
$$\leftrightarrow \frac{(X+P)^2}{\left(Y+\sum_{k'\neq k}^{K} Z^2\right)+\left(Q+\sum_{k'\neq k}^{K} R^2\right)+2\sum_{k'\neq k}^{K} ZR} > k_1$$
$$\leftrightarrow (X+P)^2 > X^2 + P^2\frac{k_1}{k_2} + 2k_1\sum_{k'\neq k}^{K} ZR$$
$$\leftrightarrow 2XP > P^2\left(\frac{k_1}{k_2}-1\right) + 2k_1\sum_{k'\neq k}^{K} ZR$$

Replacing the expression X, P, Z, R we get condition (15). Now, we can obtain the uplink SINR as (16) and obviously this result requires less complexity than the direct calculation.

$$SINR_k = \frac{(X+P)^2}{\frac{X}{k_1}+\frac{P}{k_2}+2*\sum_{k'\neq k}^{K} ZR} \quad (16)$$

Note that all quantities associated with any single SINR component of any user and at any APs are computed at the APs themselves and sent back to the CPU as inputs to the Acces algorithm. Detection, which leads to a significantly simpler calculation of the SINR of each user at the CPU. Specifically, if the SINR is calculated directly at the CPU, then checking the connection condition will have a computational complexity of $O\{4MK^2\}$, while, if using condition (15), the complexity will be $O\{(4M+k+3)\,K\}$.

C. Access Detection Algorithm

Since the globally optimal solution for the problem of finding the connection matrix A has extremely high computational complexity, this section will focus on providing an algorithm to find a suboptimal result with a complex much lower complexity. The main idea of the algorithm is to check the connection condition of APs with single rate from high to low, so as to ensure that each connected AP will always increase the uplink rate for the user.

1) Fixed power:

In this case, we assume that the transmit power of each user is fixed and equal to the maximum possible power ($\eta_k = 1$). Algorithm to find the connection matrix in case of fixed transmit power is described in Algorithm 1

2) Adjust the transmit power by convex problem:

In practice, we can see that when the transmit power is fixed, there will be users with very good SINR, exceeding the set QoS of the system, but there also exist users whose SINR is close to the set QoS. To solve this problem, we can adjust the transmit power of each user to increase the number of QoS satisfied users as much as possible.

Algorithm 1 Access Detection in Fixed Power case ($\eta_k = 1$)

1. Initialization: Sorted Single SINR r_{mk}.
   Channel gain: γ_{mk}.
   QoS requirement: R_{req}
2. $R_k = r_{1k}$
3. **for** $k = 1\, to\, K$ **do**
   - **if** $\eta_k \neq 0$ **then**
     - **for** $m \leq M$ **do**
       - Check connection condition in (15)
       - **if** Condition satisfy **then**
         - Update R_k, A_{mk} by (16)
         - **if** $R_k \geq R_{req}$ **then**
           - $k = k+1$
           - $m = 1$
         - **end if**
       - **else**
         - $m = m+1$
       - **end if**
     - **end for**
   - **end if**

   end for
4. Check QoS at each user
   - **if** $\exists R_k < R_{req}$ **then**
     - $k' = argmin_k R_k \,\text{and}\, R_k \neq 0$
     - $\eta_k = 0$
     - Return step 2
   - **else**
     - Return R_k, A_{mk}, η_k
   - **end if**

Let C be the vector representing the network connection status of users:

$$C_k = \begin{cases} 1, \text{ if connected} \\ 0, \text{ if not connected} \end{cases}$$

The Convex problem is represented as follows:

$$\begin{aligned} \underset{\eta_k}{\text{minimize}} \quad & 0 \\ \text{subject to} \quad & \sqrt{\eta_k}\sum_{m=1}^{M}(A_{mk}\gamma_{mk}) \geq \left(2^{R_{req}-1}\right) IN_k, \ \text{ if } C_k \neq 0 \\ & 0 \leq \eta_k \leq 1 \end{aligned} \quad (17)$$

Applying (17) to the algorithm to find the connection matrix and the power control coefficient, we have the following Algorithm 2:

IV. Numerical Results and Discussions

In this section we will compare the performance of Lemma method with two other methods including Fully Connected

Algorithm 2 Access Detection with Power Control

1. Initialization: Sorted Single SINR r_{mk}.
   Channel gain: γ_{mk}.
   QoS requirement: R_{req}
2. $R_k = r_{1k}$
3. **for** $k = 1\, to\, K$ **do**
   - **if** $\eta_k \neq 0$ **then**
     - **for** $m \leq M$ **do**
       - Check connection condition in (15)
       - **if** Condition satisfy **then**
         - Update R_k, A_{mk} by (16)
       - **else**
         - $m = m + 1$
       - **end if**
     - **end for**
   - **end if**

   end for
4. Check QoS at each user
   - **if** Problem (17 is not solved) **then**
     - $k' = argmin_k R_k$ and $R_k \neq 0$
     - $C_k = 0$
     - Return step 2
   - **else**
     - Return R_k, A_{mk}, η_k
   - **end if**

method and T method. With Fully Connected method is the method to connect all users to all APs (is the method is used in [2]) and T method is the method to connect each user to all APs, then gradually eliminate users that do not satisfy QoS. At the same time, we also compare the running time of the T method algorithm compared with the Brute-force algorithm to find the globally optimal connection matrix A.

A. Large-scale fading

We perform pathloss and shadow fading correlation model which is used in performance evaluation. Large-scale fading coefficient β_{mk}, pathloss and shadow fading models are given as

$$\beta_{mk} = \mathrm{PL}_{mk} 10^{\frac{\sigma_{sh} z_{mk}}{10}}, \tag{18}$$

where PL_{mk} represents the pathloss, and $10^{\frac{\sigma_{sh} z_{mk}}{10}}$ is the shadow fading with standard deviation σ_{sh} and $z_{mk}\ \mathcal{N}(0,1)$.

1) Pathloss model: We use the three-slope model to define the large-scale fading coefficients, the path loss exponent equals to 3.5 if the distance between m^{th} AP and k^{th} user $(\text{performance by } d_{mk})$ greater than d_1, equals 2 if $d_1 \geq d_{mk} \geq d_0$ and equals 0 if $d_{mk} \leq d_0$. When $d_{mk} \geq d_1$, we use Hata-COST231 propagation model. More specifically, the pathloss (dB) is given by [3]:

$$\mathrm{PL}_{mk} = \begin{cases} -L - 35\log_{10}(d_{mk}), \text{ if } d_{mk} > d_1, \\ -L - 15\log_{10} l(d_1) - 20\log_{10}(d_{mk}), \text{ if } d_0 < d_{mk} \leq d_1 \\ -L - 15\log_{10}(d_1) - 20\log_{10}(d_0), \text{ if } d_{mk} \leq d_0, \end{cases}$$

with

$$L \triangleq 46.3 + 33.9\log_{10}(f) - 13.82\log_{10}(h_{\mathrm{AP}}) - (1.1\log_{10}(f) - 0.7)\, h_{\mathrm{u}} + (1.56\log_{10}(f) - 0.8),$$

where f is the carrier frequency (MHz), whereas h_{AP} is height of AP antenna (m) and h_u is the height of user antenna. The pathloss PL_{mk} is continuous function. Note that when $d_{mk} \leq d_1$, there is not shadowing.

2) Shadow correlation mode: Most of the previous works assumed that shadowing coefficient is uncorrelated. However, in practice, transmitters/receivers that are so close vicinity of each other can be surrounded by common obstacles, and so, shadowing coefficients is correlated. This correlation can significant influence to system performance. For shadow fading coefficient, we use a model with two components [4]:

$$z_{mk} = \sqrt{\delta} a_m + \sqrt{1-\delta} b_k, \quad \text{with} \quad m = [1, 2, \ldots, M]; k = [1, 2, \ldots, K], \tag{19}$$

where $a_m\ \mathcal{N}(0,1)$ and $b_k\ \mathcal{N}(0,1)$ is 2 independent random variable. The variable a_m models the contribution of of shadow fading that result from obstructing objects in the vicinity of m^{th} AP, and which influences the channels from that AP to all users in the same way. The variable b_k models the contributions of shadow fading that result from obstructing objects in the vicinity of k^{th} user, and which affects the channels from that user to all APs in the same way. When $\delta = 0$, shadow fading from a given user is the same to all APs. Oppositely, when $\delta = 1$, shadow fading from a given AP is the same to all users, but different users are affected by different shadowing. Changing δ in range 0 and 1 trades off between 2 extremes.

The covariance function of a_m and b_k is given as

$$\mathbb{E}\{a_m a_{m'}\} = 2^{-\frac{d_{a\{m,m'\}}}{d_{\mathrm{cor}}}}; \quad \mathbb{E}\{b_k b_{k'}\} = 2^{-\frac{d_{u(k,k')}}{d_{\mathrm{cor}}}}, \tag{20}$$

where $d_{a(m,m')}$ and $d_{a(k,k')}$ is geographical distance between m^{th} and m'^{th} APs and k^{th} and k'^{th} users, respectively. d_{cor} is decorrelation distance which depend in environments. Normally, decorrelation distance is to be approximately 20(m) (19.6(m) at 5GHz and 20.2(m) at 2GHz) [5]. A shorter decorrelation distance corresponds to a low level of environmental stability.

B. Parameter and set up

In all examples, we choose summarized coefficients in Table II. The length of each coherence interval is τ_c. We use τ^{p_u} samples for uplink training phase. In this study $\tau_c = 200$ and $\tau^{\mathrm{p}_u} = 10$ samples, corresponding to bandwidth

TABLE I
PARAMETER SETTING FOR SIMULATION

Parameter	Value
Carried frequency	1.9 GHz
Noise Figure	9dB
User antenna height	1.65m
AP antenna height	15m
$\bar{p}^{\mathrm{CF}_d}$, p_p^{CF}	200, 100 mW
σ_{sh}	8dB
D, d_1, d_0	1000, 50, 100 m
R_{req}	1.5850 b/s/Hz m

TABLE II
RUNTIME

Algorithm	Runtime
Brute-Force	10.337
Lemma method	3.9949×10^{-4}

200MHz, coherence time 1ms and choose $B = 20$MHz. When comparing performance in all cases, we consider 200 cases of random distribution of AP/user and shadowing.

The number of users, APs and antennas for each instance is given by:

- The case of changing the number of users: M = 200, N = 2.
- The case of changing the number of APs: K = 60, N = 2.
- The case of changing the number of users: M = 200, K = 60.

In the case of checking the computational complexity, since the Brute-force algorithm has too much complexity, we will consider a simple system consisting of M = 4, K = 4, N = 2. Due to the number of users too few, so in this section we do not consider the performance of the two algorithms to find connection matrix A.

C. Simulation Result and Discussion

To calculate the runtime of two algorithms T method and Brute Force method, we use matlab2020b with hardware configuration including CPU Xeon E2236, 32 GB RAM, GPU RTX3070. Runtime calculation and number of users satisfy QoS results are given by the following table and figure:

We see that Lemma method gives nearly 60000 times faster running time than Brute-Force. This result is due to two main reasons:

- Difference in the number of cases to consider: We see that in the worst case, Lemma method only has to consider at most MK^2 cases, while Brute-Force always has to consider 2^{MK} cases.
- Difference in computational complexity: Since it has to compute for all possible cases, the Brute-Force algorithm is forced to calculate the SINR directly using the formula given by (11), which As we have seen in section III.B, the direct computation of SINR is much more complicated than the method using condition (15).

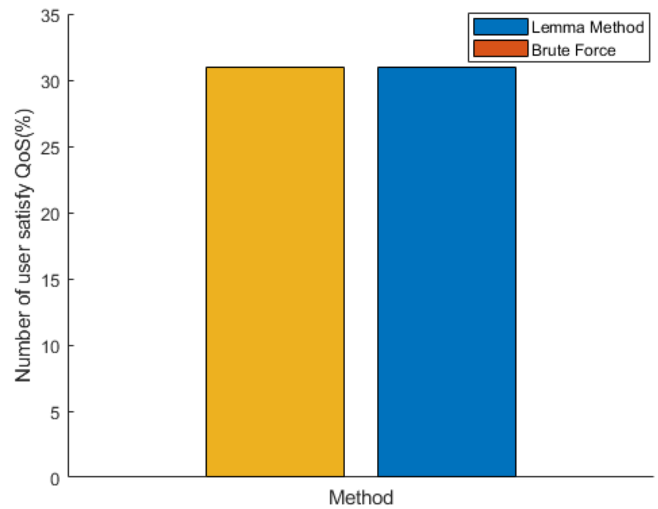

Fig. 1. Number of users satisfy QoS in Brute Force and Lemma Method **??**

Next, we consider the simulation results to compare the performance between Lemma method, T method and Fully Connected method. We see that the Lemma method gives a higher performance than the other two methods, specifically as follows:

- When changing the number of users: The performance of Lemma method always maintains a difference of 7-8 % compared to the other two methods.
- When changing the number of APs: The performance of Lemma method always maintains a difference of 7-8 % compared to the other two methods.
- When changing the number of Antennas: The performance of the Lemma method increases gradually with increasing the number of antennas, the difference increasing from 3 % in the case of single antennas to 7-8 % in the case of 5 antennas.

From the above results, we can see that Lemma method can really improve the performance of the system through the connection condition (15) is not too complicated.

V. CONCLUSION

In this study, we introduce a method to select the connection between users and APs in Cell-free Massive MIMO system. Specifically, we provide a connection selection algorithm based on examining single-rate APs with each user in order from highest to lowest by a connection condition that is not too complicated. In this way, the connection state of each pair of user-APs will be determined quickly, although a globally optimal connection matrix cannot be found, but it is still good enough when compared to the Fully case. Connected. Overall, we can see that the Lemma method gives us a solution with good enough performance with a moderate level of computational complexity.

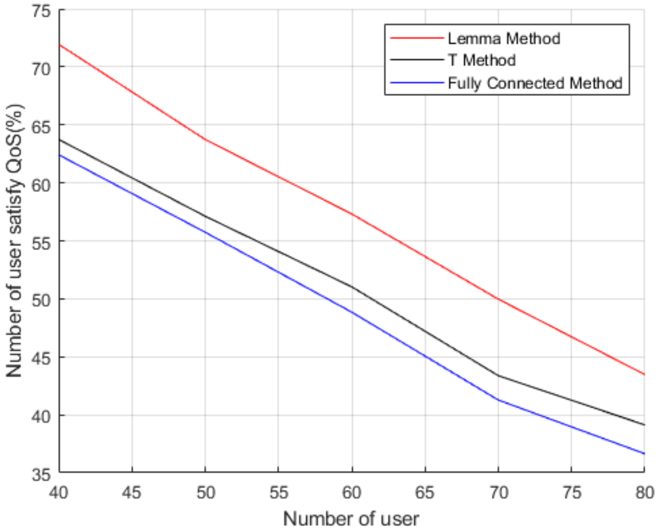

Fig. 2. System performance in case of changing number of users and fixed transmit power

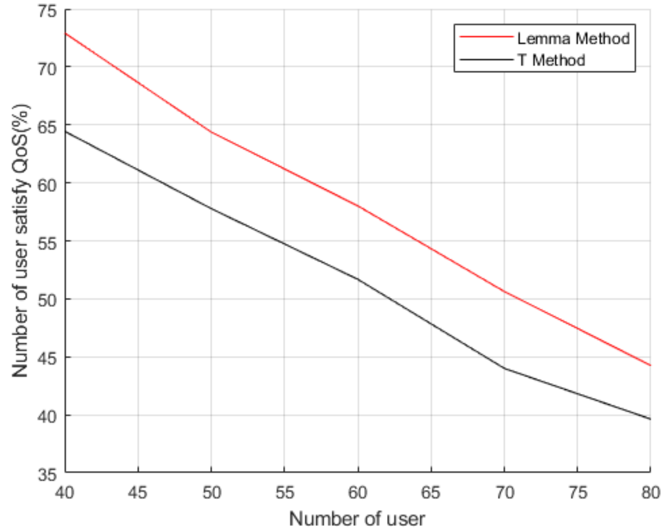

Fig. 3. System performance in case of changing number of users and power control factor is adjusted through convex problem 17

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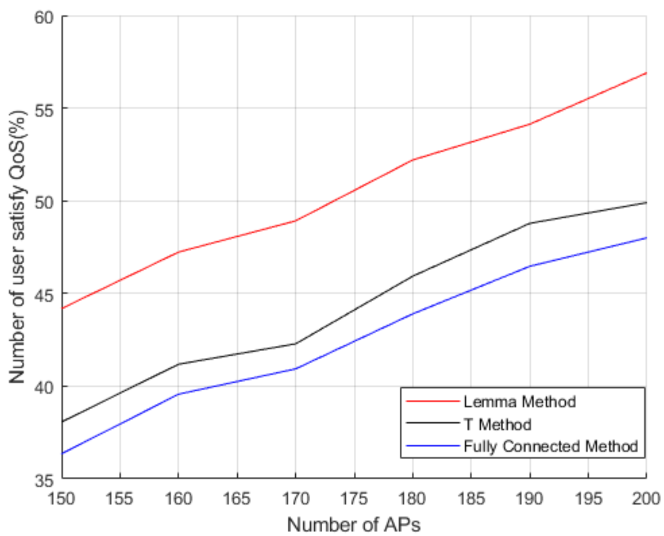

Fig. 4. System performance in case of changing number of APs and fixed transmit power

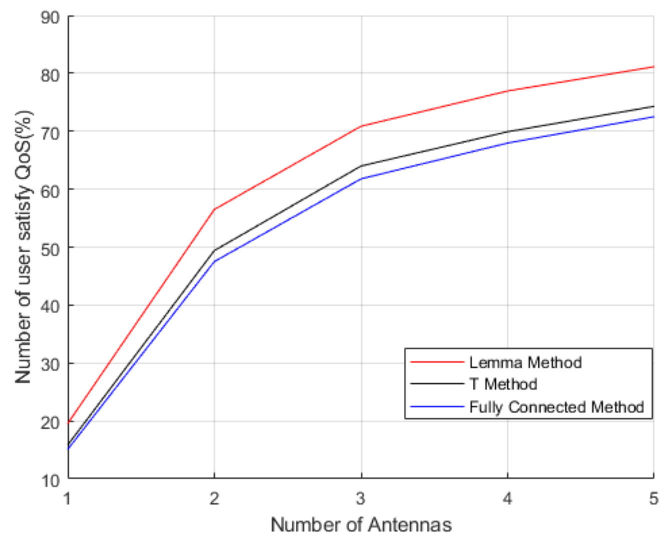

Fig. 6. System performance in case of changing number of Antennas and fixed transmit power

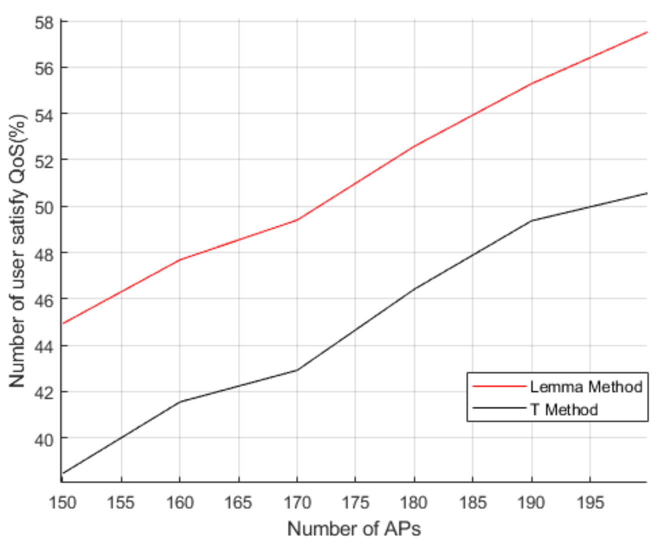

Fig. 5. System performance in case of changing number of APs and power control factor is adjusted through convex problem 17

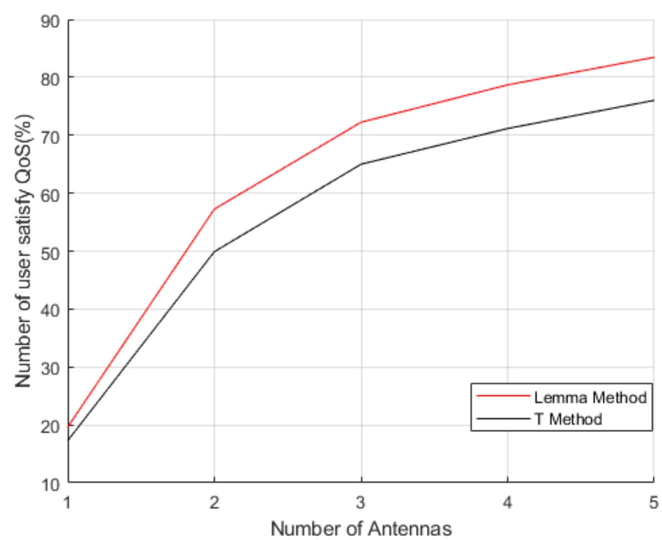

Fig. 7. System performance in case of changing number of Antennas and power control factor is adjusted through convex problem 17