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JOINT POWER CONTROL AND LSFD FOR WIRELESS-POWERED CELL-FREE MASSIVE MIMO

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Abstract
In this project, we study the uplink (UL) and downlink (DL) spectral efficiency (SE) of a cell-free massive multiple input-multiple-output (MIMO) system over Rican fading channels. The phase of the line-of-sight (LoS) path is modeled as uniformly distributed random variable to take the phase-shifts due to mobility and phase noise into account. Considering the availability of prior information at the access points (APs), the phase-aware minimum mean square error (MMSE), non-aware linear MMSE (LMMSE), and least-square (LS) estimators are derived. The MMSE estimator requires perfectly estimated phase knowledge whereas the LMMSE and LS are derived without it. In the UL, a two-layer decoding method is investigated to mitigate both coherent and non-coherent interference. Closed form UL SE expressions with phase-aware MMSE, LMMSE, and LS estimators are derived for maximum-ratio (MR) combining in the first layer and optimal large-scale fading decoding (LSFD) in the second layer. In the DL, two different transmission modes are studied: coherent and non-coherent. Closed-form DL SE expressions for both transmission modes with MR precoding are derived for the three estimators. Numerical results show that the LSFD improves the UL SE performance and coherent transmission mode performs much better than non-coherent transmission in the DL. Besides, the performance loss due to the lack of phase information depends on the pilot length and it is small when the pilot contamination is low.

Keywords: Publication, Green Energy, Emerging Advances and ICEAAGE.

I. Introduction

Wireless technology is the most note worthy advancement now a days , with widespread access that has become an integral part of society as crucial as electricity and the connectivity itself impels developments. Wireless communication services are accessible and pervasive in all walks of life of all the people globally, thanks to a cellular wide area, local area networks, and satellite services. Currently, wireless communication techniques can differentiate in either single carrier modulations or Multi-Carrier Modulations (MCM).

Evolution of Cellular System

New technologies call for new demands, but we are not sure about the consumers about what applications they are using or asking for. Wireless technology was rapidly undergoing development for the past few years, varying from limited data rates to real-time implementations due to huge needs. Viable data has become more significant, and more sophisticated wireless systems are underway.
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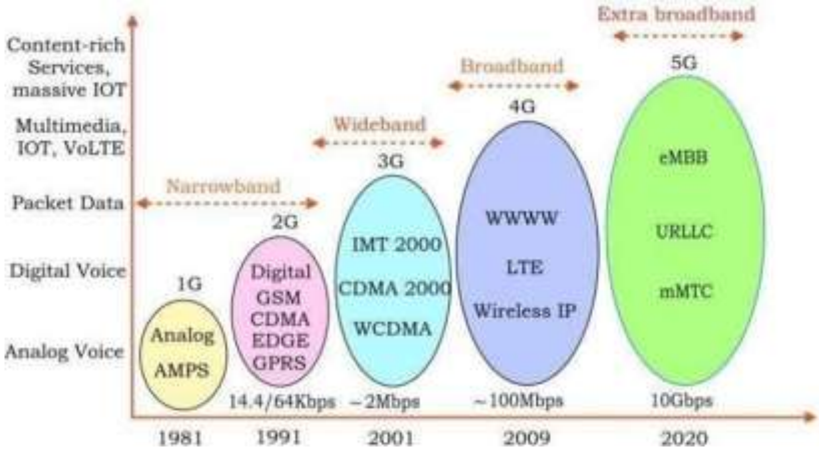

. Evolution of Cellular Systems

Conventional MIMO versus Massive MIMO

In Wireless Communications MIMO technology drawn substantial interest, because it enables substantial changes in data throughput and the connectivity area without increasing bandwidthortransmittingcapacityMIMOtechnologyhasattainedconsiderableattentioninwireless networking since the data output, and connection range has increased considerably, and no need for bandwidthincreased,orpowertransmits.Fig1.3showstheconventionalMIMOandmassiveMIMO with M and K transceiver antennas. Today the Massive MIMO is widely accepted for its distinctive spectral performance, reliability, and overall capabilities in TDD/FDD systems, and both in academia and industry.

Introduction to Massive MIMO

A cellular network's highly spectrally pre-eminence tier is summarized as follows: It allows formultiplexinggainsutilizingSDMAbyconnectingmanyUEstothecorrespondingtime-frequency service. Furthermore, it has more base station antennas than user equipment per cell, as seen in Fig 1.3, to effectively eliminate interference. The BS should intensify the number of antennas proportionally if the predicted number of UEs in a cell increases.

The multiplexing and de-multiplexing signal processing of the base station is provided with multiplicative antennas and CSI due to TDD methods, calculating the terminals' pilots and reciprocating the uplink and downlink transmissions.

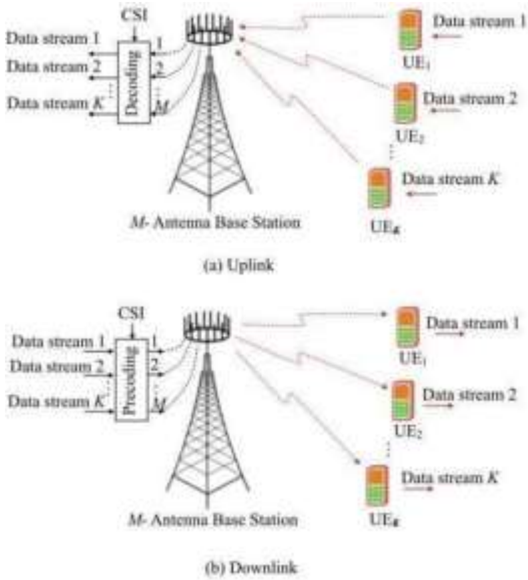

Illustration of the basic Massive MIMO

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II. PROPOSEDSYSTEM

Cell-free massive MIMO refers to a distributed MIMO system with many APs that jointly serve a smaller number of user equipment's (UEs). The APs cooperate via a front haul network to spatially multiplex the UEs on the same time-frequency resource, using network MIMO methods that only require locally obtained channel state information (CSI).In its canonical form, cell-free massive MIMO uses MR combining because of its low complexity. Since MR combining cannot suppress the interference well, some APs receive more interference from other UEs than signal power from the desired UE.The LSFD method is proposed in and to mitigate the interference for co-located massive MIMO systems. This method generalized for more realistic spatially correlated Rayleigh fading channels with arbitrary first- layer decoders. The two-layer decoding technique is first adapted to cell-free massive MIMO networks in for a Rayleigh fading scenario. In the concurrent paper, the LSFD method is studied in a setup with Rician fading channels where the LoS phase is static. Joint transmission from multiple APs can be either coherent (same data from all APs) or non-coherent (different data).Only the former has been considered in cell-free massive MIMO, but it requires that the APs are phase-synchronized. A synchronization method is outlined in without validation.

In densely deployed systems, like cell-free massive MIMO, the channels typically consist of a combination of a semi deterministic LoS path and small-scale fading caused by multipath propagation, which can be modelled as Rician fading. A small change in the UE location may result in a significant phase-shift of the LoS component, but no change in amplitude. For instance, if the UE moves half a wavelength away from the AP, the phase of the channel response changes by $\pm\pi$. Similarly, hardware effects such as phase noise may create severe shift in the phase. These effects are usually neglected in the analysis of Rician fading channels by assuming a LoS path with static phase. Especially in high mobility scenarios, the phase shift in LoS path may have a large impact on system performance. Recently, studied a cell-free network that supports both unmanned aerial vehicles (UAVs) and ground UEs where the channels between AP-UAV pairs have Rician distribution with uniformly distributed phase on the LoS paths. Each AP needs to learn the channel statistics of each that it serves, as well as the statistics of the combined interfering signals, if Bayesian channel estimators are to be used.

The large-scale fading coefficients can be estimated with a negligible overhead since the coefficients are deterministic; several practical methods to estimate these coefficients using uplink pilots are presented. However, the phase-shifts are harder to estimate since they change as frequently as the small-scale fading.

System Model

We consider a cell-free Massive MIMO system with M APs and K UEs. All APs and UEs are equipped with a single antenna. The multi-antenna AP case can be straight forwardly covered by treating each antenna as a separate AP,if it is assumed that there is no correlation between the small-scale fading coefficients (or phase-shifts). However, for a more realistic analysis, single-antenna results can be generalized to multiple antenna case by taking the spatial correlations between antennas into account. It will result in non-diagonal covariance matrices. The channels are assumed to be constant and frequency- flat in a coherence block of length τ_c samples (channel uses). The length of each coherence block is determined by the carrier frequency and external factors such as the propagation environment and UE mobility. The channel $h_{m\,k}$ between UE k and the AP m is modeled as

$$h_{m,k} = \bar{h}_{m,k} e^{j\phi_{m,k}} + g_{m,k}, \quad (1)$$

Where $g_{m,k} \sim \mathcal{N}_C(0, \beta_{m,k})$, the mean $\bar{h}_{m,k} \geq 0$ represents the LoS component, and $\phi_{m,k} \sim U[-\pi,\pi]$ is the phase-shift. The small-scale fading from non-LoS (NLoS) propagation has a variance $\beta_{m,k}$ that models the large-scale fading, including geometric path loss and shadowing. Note that (1) is a Rician fading model since $|h_{m,k}|$ is Rice distributed, but $h_{m,k}$ is not Gaussian distributed as in many prior works that neglected the phase shift. We assume that $h_{m,k}$ is an independent random variable for every m=1,...,M,k=1,..., K and the channel realization $h_{m,k}$ in different coherence blocks are i.i.d. All APs are connected to a central processing unit (CPU) via a front haul network that is error free. The system operates in time division duplex (TDD) mode and the uplink (UL) and DL channels are estimated by exploiting only UL pilot transmission and channel reciprocity.

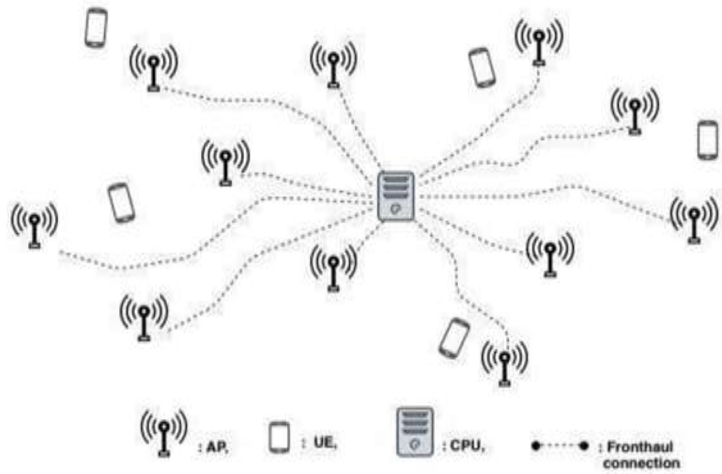

Illustration of a cell-free massive MIMO network

Proposed Method

Fig shows the system block diagram of a baseband OFDM system with MMIMO antennas. Denote Xl(l=0,1, 2,…,N-1) as the modulated symbols on the lt h transmitting subcarrier of OFDM symbol at transmitter, which are assumed independent, zero-mean random variables, with average power. The complex baseband OFDM signal at output of the IFFT can be written as

$$x_n = \frac{1}{\sqrt{N}}\sum_{l=0}^{N-1} X_l\, e^{\frac{j2\pi nl}{N}}, n = 0,\ldots, N-1$$

Where N is the total number of sub carriers in an OFDM frame and the OFDM symbol duration is T seconds. At the receiver, the received OFDM signal is mixed with the local oscillator signal, with the frequency offset deviated from compared to the carrier frequency of the received signal owing. The received signal is given by

$$y_n = (x_n \otimes h_n)e^{\frac{j2\pi n\Delta fT}{N}} + z_n$$

Where fn represents the channel impulse $e^{j\frac{2\pi}{N}n\Delta fT}$ response, is the corresponding frequency offset of received signal at the sampling instants with Δft being the frequency offset to subcarrier frequency spacing ratio, and zn is the AWGN.Respectively, while $\otimes$ denotes the circular convolution. Assuming that a cyclic prefix is employed, the receiver has perfect time synchronization. Note that a discrete Fourier transform (DFT) of the convolution of two signals in time domain is equivalent to the multiplication of the corresponding signals in the frequency domain. Then the output of the FFT in frequency domain signal on the kt receiving subcarrier becomes

$$= X_k H_k S(0) + \sum_{l=0, l\neq k}^{N-1} X_l H_l S(l-k) + Z_k$$

$$Y_k = \sum_{l=0}^{N-1} X_l H_l\, S(l-k) + Z_k, k = 0,1,2,\ldots, N-1$$

The first term of Equation is a desired transmitted data symbol and these condterm represents the ICI from the undesired data symbols caused by other subcarriers in OFDM symbols. hk, is the frequency-domain channel impulse response and zk denotes the frequency domain of zn.Thesequence $s(l-k)$is defined as the ICI coefficient between $kth$and lthsubcarriers, which can be expressed as given.

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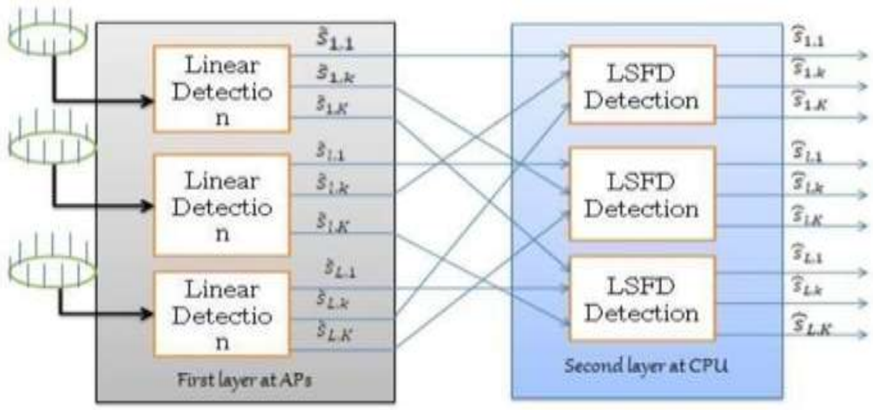


Massive MIMO architecture

Now, ICI mitigation scheme in MMIMO systems is presented as shown in Fig. The modulated symbols $X_l(l = 0,1,2,\cdots,N-1)$ are encoded with the Alamut space-time-block coding (ASTBC).The transmitted frequency domain signal on l^{th} transmitting sub carrier from an antenna one is denoted by $A_{1,l} = (X_0, 0, X_1, 0, \cdots, X_{N/2-1}, 0$
$l = 0,\ldots, N-1$, respectively and from antenna two is denoted by Assuming that CP is employed, the receiver has the perfect time synchronization. Note also that the frequency offset is constant over two-path time interval. The time-domain received signal is expressed by

$$y_n = \left(a_{1,n} \otimes h_{1,n} + a_{2,n} \otimes h_{2,n}\right) e^{\frac{j2\pi n\varepsilon T}{N}} + z_n$$

Then the frequency-domain received signal model of a primary path on the *h* receiving subcarrier expressed in Equation is

$$Y_k = \sum_{l=0,l\neq k}^{N-1} A_{1,l} H_{1,l} S(1, l-k) + \sum_{l=0,l\neq k}^{N-1} A_{2,l} H_{2,l} S(2, l-k) + Z_k$$

An equalizer is a type of filter circuit which is connected at the front end of the wireless receiver to compensate the variations in the amplitude and time delay characteristics of the received signal. The equalizer should follow the time varying characteristics of the channel due to the nature off ading.This equalizer can be either time varying or adaptive. An adaptive equalizer has training mode and tracking mode of operations.

Least-Square (Ls) Algorithm

The Least-Square (LS) method is a mathematical procedure to identify the best fit line to the data. It is used to estimate the parameters that fit a function (x) for a set of data x1, x2, xn.For a best fitting of the given data, LS method decreases the sum of squared residuals which is also described as Sum of Squared Errors (SSE). It is given by Equation

$$SSE = \sum_{i=1}^{i=n} r_i^2$$

Where is the residual. It is represented by the following equation.

$$r_i = y_i - f(x_i)$$

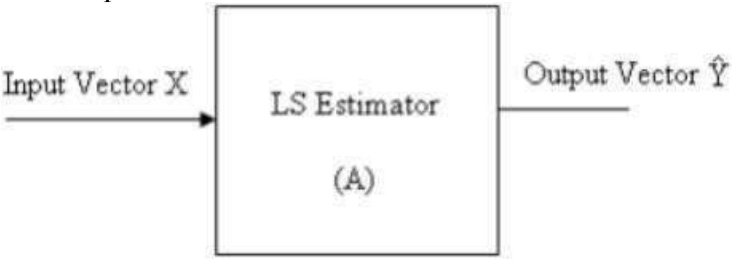
Here, xiis a pair of data, and f(xi) is the equalized function. There may be an error between the real data and the equalized data.This LS method can be either in linear or non-linearmode.TheLinear LS method is one of the most common linear regression methods used to find the best fitting of data as straight-line. The equalized function is given by Equation

$$f(x_i) = ax_i + b$$

$$SSE = \sum_{i=1}^{i=n} (y_i - (ax_i + b))^2$$

Where a, b are the constants. This method is used to minimize the sum of squared errors which are denoted by Equation.

To minimize this function, the partial derivative of with respect to a and b are zero. The block diagram of LS equalizer is shown



Let it be considered a linear LS equalized function which is represented in the form given in Equation

$$y_i = a_1 \times x_1 + a_2 \times x_2 + \cdots + a_m \times x_m + r$$

The above function can be described in the matrix format which is given as

$$Y = [X]A + R$$

Where X is the input matrix of the data set,Y is the output vector, is an unknown vector, and a residual vector.
Form of Equation. The unknown vector A is represented as

$$A = [X]^{-1}Y$$

The above equation is used as a basic equation to estimate the channel coefficients in the Shannel equalization of Massive MIMO system.

Minimum Mean Square Error (MMSE) Algorithm

The MMSE algorithm is used as a mathematical channel equalization model to find channel coefficients. This algorithm minimizes the Mean Square Error (MSE). It can be expressed as quadratic cost function mathematically. Let be the(nX1) dimension of input vector and y be the (mX1)dimension of output vector and be the equalized vector. There is an error between the original input and the equalized output. This equalization error is given by Equation.

$$e = x - \hat{x}$$

The trace of error covariance matrix which is shown in Equation.

$$MSE = tr\{E[(\hat{x} - x)(\hat{x} - x)^T]\}$$

If the input vector is a scalar quantity, then the MSE is rewritten as

$$MSE = E[(\hat{x} - x)^2]$$

If the equalized vector has n predictions, then the MSE is represented as

$$MSE = \frac{1}{n}\sum_{i=1}^{i=n}(\hat{x} - x)^2$$

Also, the MMSE is identified as the minimum value from the group of mean square errors. It is given as

$$MMSE = \arg(\min MSE)$$

The above equations are used as basic equations to estimate the channel coefficients in the MMSE channel equalization of Massive MIMO system.

Fc-Af Decoding

We use these coefficients as the CSI.The combiner combines the received signal asfollows

$$x_1' = h_1^* r_1 + h_2 r_2^* = (\alpha_1^2 + \alpha_2^2)x_1 + h_1^* n_1 + h_2 n_2^*$$

$$x_2' = h_2^* r_1^* - h_1 r_2^* = (\alpha_1^2 + \alpha_2^2)x_2 + h_2^* n_1 - h_1 n_2^*$$

And sends them to the maximum likelihood detector, which minimizes the following decision metric, Expanding the above equation and deleting terms that are independent of the code words, the above minimization reduces to separately minimizing.

$$|r_1 h_2^* - r_2^* h_1 - x_2|^2 + (\alpha_1^2 + \alpha_2^2 - 1)|x_1|^2$$

For detecting x1

$$|r_1 h_2^* - r_2^* h_1 - x_2|^2 + (\alpha_1^2 + \alpha_2^2 - 1)|x_2|^2$$

For decoding x2

Hence, we obtain a transmit diversity of two. Consider two distinct code sequences are generated by the inputs (x_1, x_2) and (x'_1, x'_2)respectively, where

The code word difference matrix is given by

$$(x_1, x_2) \neq (x'_1, x'_2)$$

$$G(x,x') = \begin{bmatrix} x_1 - -x'_1 & -x_2^* - x_2'^* \\ x_2 - x'_2 & x_1^* - x_1'^* \end{bmatrix}$$

Since, the rows of the code matrix are orthogonal; the rows of the code word difference matrix are orthogonal as well. The code word distance matrix is given by,

$$A(x,x') = B(x,x')\, B^H(x,x')$$

$$= \begin{bmatrix} |x_1 - x'_1|^2 + |x_2 - x'_2|^2 & 0 \\ 0 & |x_1 - x'_1|^2 + |x_2 - x'_2|^2 \end{bmatrix}$$

Since, $(x_1, x_2) \neq (x'_1, x'_2)$,the distance matrixes of any two distinct codeword have a full rank of two. Alamut scheme gives diversity two. The determinant of matrix is given by

$$det(A(x,x')) = (|s_1 - s'_1|^2 + |s_2 - s'_2|^2)^2$$

The code word distance matrix at above equation has two identical Eigen values. The minimum Eigen value is equal to the minimum squared Euclidian distance in the signal constellation. Hence, the minimum distance between any two transmitted code sequences remains the same as in the un-coded system, and this implies that the coding gain is one.

It is a simple form of equalizer in which the equalizer coefficients cn force the impulse response of the equalizer as zero. The frequency response of the equalizer is assumed as Heq(f), the frequency response of the channel is Hch(f) and the symbol duration is T.The combined channel response with equalizer should satisfy the Nyquist's criterion. This is mentioned by Equation (30).

$$H_{ch}(f)\, H_{eq}(f) = 1,\ f < 1/2T$$

An Adaptive equalizer is an inverse filter with N+1 taps, N delay elements, and N+ 1 weights. The adaptive equalizer's block schematic is shown in an adaptive algorithm that is used to update the weights continuously to make better equalizer output with fewer errors. This adaptive algorithm is restricted by an error signal ek, where k is the time index. This ek is the difference between the output of the equalizer and the output of the transmitted signal. This adaptive algorithm uses the error signal ek and the weight coefficient wk to make minimum cost function with the help of several iterations. Let the equalizer input be xk and the weight coefficient vector be wk, and the equalizer output is the inner product of xk and wk. It is given by Equation (31).

$$y_k = \langle x_k , w_k \rangle$$

The error signal ek and the Mean Square Error (MSE) are represented by Equations respectively.

$$e_k = d_k - y_k$$

Where dk is the transmitted data

$$MSE = E[(d_k - y_k)]^2$$

Since yk depends on the weight function wk,MSEis also related to the weight function wk.

$$[X]^T [X] A = [X]^T Y$$

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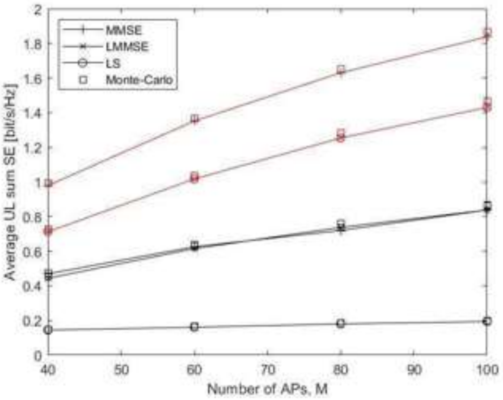
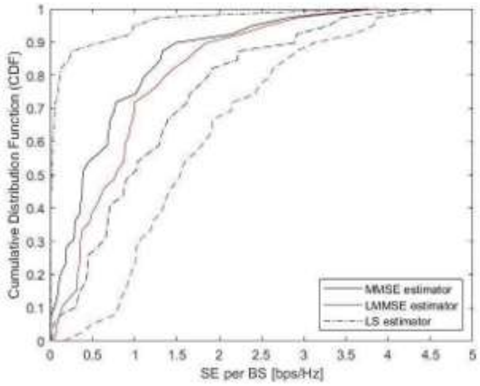
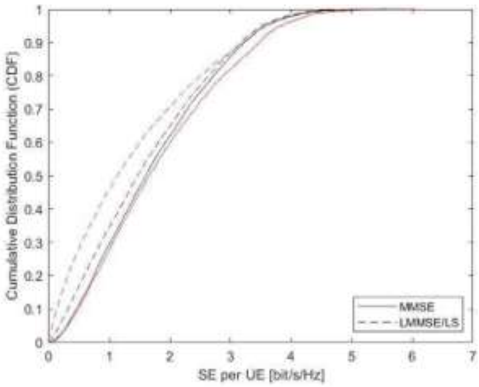
III. RESULT

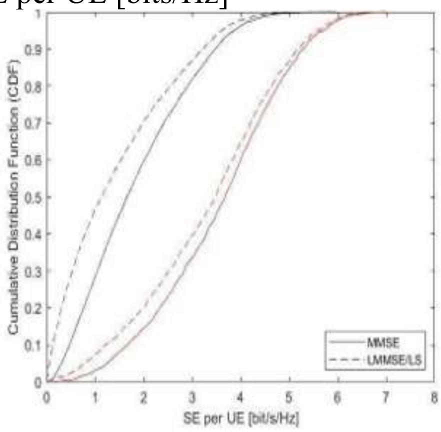




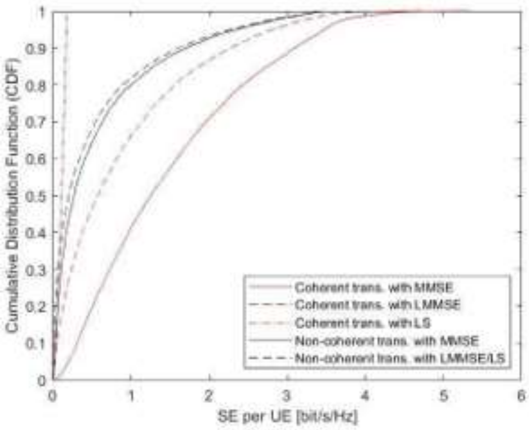
Distribution Function (CDF) vs SE per BS [bps/Hz]   Average ULsumSE (bit/HZ) VS number of Aps,M

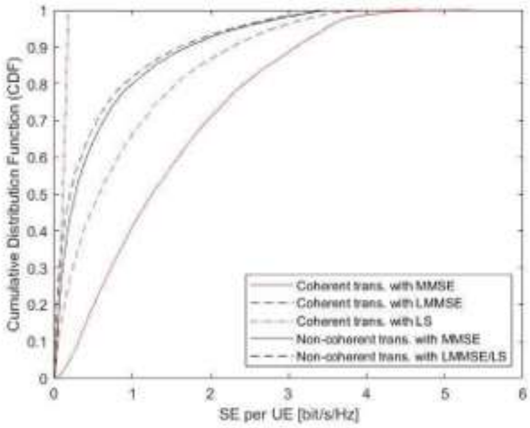
Cumulative Distribution Function (CDF) vs SE per UE [bits/Hz]





Cumulative Distribution Function (CDF) vs SE per UE [bits/Hz]   Cumulative Distribution Function (CDF) vs SE perUE[bit/s/Hz]





Cumulative Distribution Function (CDF) vs SE perUE[bit/s/Hz]   Cumulative Distribution Function (CDF) vs SE per UE[bit/s/Hz]

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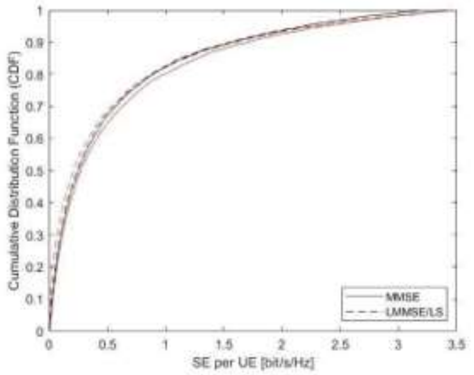
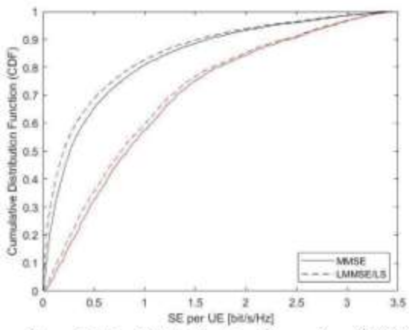


Cumulative Distribution Function (CDF) vs SE per UE [bits/Hz]



Cumulative Distribution Function (CDF) vs SE per UE[bit/s/Hz]

IV. CONCLUSION

This work studied the SE of a cell-free massive MIMO system over Rician fading channels. The phase of the LoS path is modeled as a uniformly distributed random variable to take phase-shifts due to mobility and phase noise into account. To determine the importance of knowing the phase, the phase aware MMSE, non-aware LMMSE, and LS estimators were derived. In the UL, a two-layer decoding method was studied to mitigate both coherent and non coherent interference. We observed that the LSFD method provides a substantial gain in UL SE for all estimators and should therefore always be used in cell-free massive MIMO.

Furthermore, the performance losses because of unavailable phase knowledge depend on the pilot length. If there is no strongly interfering user, the LoS and NLoS paths can be jointly estimated without having to know the phase. In the tested scenarios, we observed 6.9% performance loss for low pilot contamination and 24.8% for high pilot contamination. In the DL part,coherent and non-coherent transmission were studied. We noticed that the losses from the lack of phase knowledge are13.4%and 2.4% for coherent and noncoherent transmission respectively in the tested scenarios with low pilot contamination. When we reduced the pilot length, its loss increased up to 42.6%. Therefore, the pilot length should be adjusted by taking the phase shifts into account in high mobility or low-quality hardware scenarios. To deal with the cases where there are not enough pilots, methods to explicitly estimate the phases could be considered in future work. Besides, the coherent transmission performs much better than the non-coherent one, which is the reason of its wide use in the cell-free literature.

V. FUTURESCOPE

This work described the effectiveness of Massive MIMO system with the enhancement of SE and UE in presence of AWGN and frequency selective Rayleigh fading channel. A combined scheme of Doubly EM based equalizer-with ICI mitigation approach is employed for enhancing the performance of Massive MIMO system. In addition, this algorithm reduced the complexity and processing delay by improving BER performance of Massive MIMO system. However, the weights utilized in SE and UE expression are not optimal and further there is a lack of translation invariance. Thus, it is required to address these issues to maximize the performance of Massive MIMO system for 5G wireless networks. The combination of joint power control and least squares frequency-domain (LSFD) techniques for wireless powered cell-free massive MIMO projects holds great promise for the future. This approach offers several advantages in terms of energy efficiency, interference mitigation, spectral efficiency, and robustness to channel variations. By incorporating joint power control algorithms, the system can optimize power allocation across the network, leading to reduced energy consumption and improved overall efficiency. However, the realization of these benefits depends on factors like research advancements, standardization, commercial viability, and industry adoption.

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