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Unified Channel Estimation and Scheduling for Massive MIMO Systems

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Abstract: - **This paper proposes a unified channel estimation scheme for multiuser massive multiple input multiple output (MIMO) systems in time-varying environment. In this paper, a new discrete Fourier transform (DFT) based spatial-temporal basis expansion model (ST-BEM) is introduced to mitigate the training overhead and feedback cost by reducing the dimensions of uplink and downlink channel. This model is suitable for both time division duplex (TDD) and frequency division duplex (FDD) systems. A new greedy user scheduling algorithm is also introduced to improve the Spectral efficiency. Various simulation results are provided to demonstrate the effectiveness of the proposed method.**

Keywords: - **Massive MIMO, Discrete Fourier Transform (DFT), ST-BEM, FDD, TDD.**

I. INTRODUCTION

One of the most important physical layer techniques in 5G communication is massive MIMO or large scale multiple input and multiple output [8]. It can simultaneously serve tens of terminals in the same frequency-time with the help of hundreds of antennas located in Base Station (BS) side that provides robustness, high Energy efficiency and Spectral efficiency [9]. To utilize the benefits of massive MIMO effectively, the perfect channel state information (CSI) for both Uplink and downlink should be acquired by Base station. Usually channel is estimated via pilot sequences. But in massive MIMO it leads to pilot overhead in downlink channel estimation because the no of training sequences should be equal to the no of transmit antennas and length of the training stream should be greater than the no of transmit antennas based on orthogonal training strategy. In uplink if the no of users or no of antennas of each user increases, then pilot overhead problem occurs. If the training sequences are Non-orthogonal, then so called pilot contamination problem occurs. These problems are diminishing the system performance. In [10] and [11], the closed-loop training schemes were applied to sequentially design the optimal pilot beam patterns. The Compressive sensing (CS)-based feedback reduction in [12] and the distributed compressive channel estimation in [3] extracted the channel sparsity to reduce large amount of measurements feeding back to the Base station. This Method requires knowledge of the sparsity level in channel matrices but it’s not an easy task to accurately acquire such information. After these types of attempts low rank channel estimation approaches are introduced. These approaches reduce the effective channel dimensions. In [1], Covariance aware pilot Assignment Strategy is used. Here uplink pilot contamination, downlink training and feedback overhead are significantly reduced. But acquisition of channel covariance matrix becomes a difficult task and it also leads to Eigen value decomposition (EVD) problem for high dimensional covariance matrices. In this paper, using antenna array theory and array signal processing we propose an alternate low rank model for massive Uniform linear array (ULA). This model is based on mean direction of arrivals and angular spread (AS) of incident signals of each user. This model is known as Spatial Basis Expansion Model (SBEM). The proposed unified transmission strategy for the multiuser TDD/FDD massive MIMO systems includes Uplink (UL) channel estimation and user scheduling for data transmission. It is shown that the Uplink channel estimation of multi users can be carried out with very few training resources, and thus, the overhead of training and feedback can be also reduced significantly. Meanwhile, the pilot contamination in UL training can be immediately relieved. To enhance the spectral efficiency during the data transmission, a greedy user scheduling algorithm is proposed where users with orthogonal spatial information are allowed to transmit simultaneously.

II. SYSTEM MODEL AND CHANNEL CHARACTERISTICS

As shown in figure.1 multiuser massive MIMO system is considered where the Base station (BS) is equipped with M (>>1) antennas in the form of uniform linear array (ULA) and K single antenna users are spread over the coverage area. The propagation from user k to BS is composed of P_r-rays (P_r>>1) due to scattering, reflection

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and refraction. The channel is considered to be time selective flat fading and it will change symbol level. It's safe to assume that the physical position of users seen by the BS is unchanged within a single block N. The corresponding M x 1 uplink channel can be expressed as,

$$h_k = \frac{1}{\sqrt{P_r}} \sum_{p=1}^{P_r} \alpha_{kp} e^{\xi_{kp}} a(\theta_{kp}) \quad (1)$$

$\alpha_{kp} \approx CN(0, \sigma_p^2)$ [Complex gain of the p[th] ray] and

$\xi_{kp} = -j(2\pi f_d nT_s \cos\varphi_{kp} + \phi_{kp})$

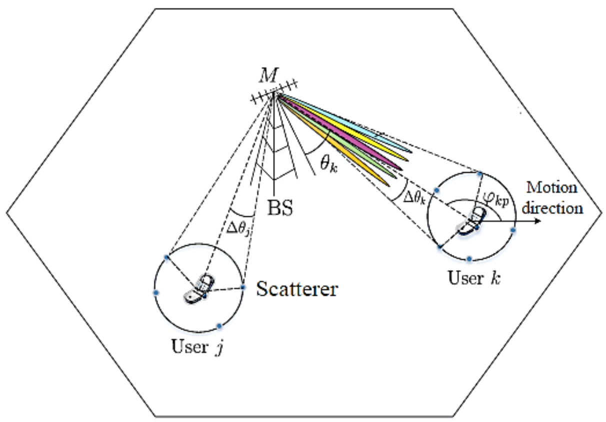

Fig.1 System model. Users are surrounded by p_r local scatterers and the mean DOA and AS f user-k are θ_k and $\Delta\theta_k$ respectively. When users are move around in a circle, the spatial AS seen by BS is generally unchanged.

where, fd is the Doppler frequency and Ts is the sampling frequency, φ_{kp} is the angle between the uplink transmitted signal and the motion direction of user-k. ϕ_{kp} signifies the initial phase, which is uniformly distributed in $[0,2\pi]$ and $a(\theta_{kp})$ is the array manifold vector and it varies based on antenna structure.

For ULA case, array manifold vector can be represented as

$$a(\theta_{kp}) = [1, e^{j\frac{2\pi d}{\lambda}\sin\theta_{kp}}, \ldots\ldots\ldots e^{j\frac{2\pi d}{\lambda}(M-1)\sin\theta_{kp}}] \quad (2)$$

where, d is the antenna spacing, λ denotes the signal carrier wavelength, θ_{kp} represents DOA of the p-th ray. The incident angular spread of user k with mean DOA (θ_k) is assumed to be limited in a narrow region, i.e., $[\theta_k - \Delta\theta_k, \theta_k + \Delta\theta_k]$ and this angular spread (AS) of each user is normally unaltered when the user moves within the circular region as shown in Fig.1.

The normalized DFT of channel vector exhibits some specific properties in massive ULA case. This property used to minimize the complexity of transceiver design. The normalized DFT can be represented as

$$fh_k = Fh_k \quad (3)$$

where, F=>MxM DFT matrix whose $(p,q)^{th}$ element is,

$$[F]_{pq} = e^{-j(\frac{2\pi}{M})pq} / \sqrt{M}$$

The propagation from user to BS is assumed to be composed of p rays. While considering single ray i.e., $h_k = \alpha_k a(\theta_k)$ and M is infinite, the normalized DFT has only one non-zero point and this point reflects the DOA of the impinging signal, namely $\theta_k = \arcsin(\frac{q\lambda}{Md})$

When M is large but not infinite, the power leakage may happen. For most cases, Non-zero point is not an integer and the channel power will leak from the $([M(d/\lambda)\sin\theta_k])^{th}$ DFT point to other DFT points. The DFT outputs are discrete samples of DTFT of a (θ_k).i.e., a sinc function, at the points of 2πq/M, q=0, 1 ….M-1. Hence the degree of leakage in fh_k is inversely proportional to the M. When M is infinite, the large but not power leakage is not a problem because most power of fh_k is still concentrates around this Non-zero point as shown in Fig.2. For the Multi-ray case, let D_k is the index set of continuous DFT points that contains η% of the channel power [7].

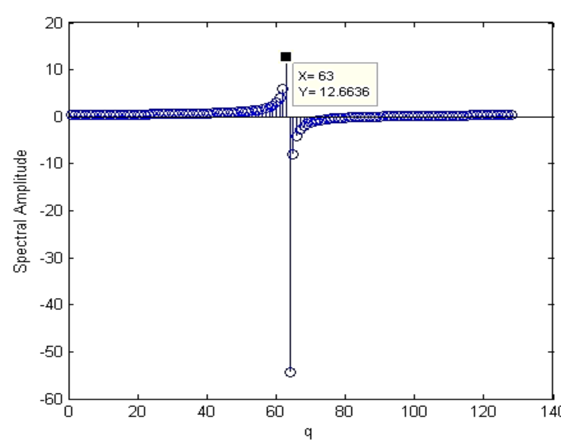

Fig.2 fhk of single incident ray with =90, M=128

It can be represented as,

$$|D_k| \le \left\lceil 2M\frac{d}{\lambda}|\cos\theta_k|\,\Delta\theta_k + 1 \right\rceil + C_{max}$$

Where, θ_k ,$\Delta\theta_k$ are DOA and AS respectively. C_{max} is the maximum no of leakage points. These indices can be viewed as spatial signature of each user. This model is known as Spatial Basis Expansion Model (SBEM). To

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deduce this, a perfect DOA is to be acquired. For this purpose, a Spatial Rotation operation is introduced. So the new channel vector can be formulated as,

$$fh_k^{ro} = F\varphi(\phi)h_k \qquad (4)$$

where,

$$\varphi(\phi) = diag\{[1, e^{j\phi}, \ldots\ldots\ldots\ldots e^{j(M-1)\phi}]\}$$

The Spatial Rotation operation, further concentrate the channel power within the fewer entries fh_k^{ro} of for a certain value of ϕ. For one-ray case, When DOA of the incident signal is not arcsin(qM/λd) for some integer q i.e., mismatched with DFT points, then power leakage will happen. Formulate a new channel vector as, $fh_k^{ro} = F\varphi(\phi)h_k$. If $\phi_k = (\frac{2\pi q}{M}) - (\frac{2\pi d}{\lambda}\sin\theta_k)$, then has only one Non-zero element and so $fh_{k,q}^{ro}$ at q, with the power leakage is eliminated, where ϕ is the shift parameter. For example in Fig.3, Spatial rotation with ϕk= 0.34375 radian can help to strengthen the channel sparsity of. fh_k. For the Multi-ray cases, a new channel vectors is formulated and define D_k^{ro} as the continuous index set such that $[fh_k^{ro}]_{D_k^{ro},:}$ contains at least η% of the channel power and search ϕ from $\frac{-\pi}{M}$ to $\frac{\pi}{M}$ and select the optimal ϕk that minimizes the $|D_k^{ro}|$ The standards are normally regulated by considering channel parameters to be estimated as fixed but here a dynamically changing parameter is considered. Define the set containing continuous τ integers as B_k^{ro} where τ is the number of channel parameters that system could handle. Then select the spatial signature set and corresponding shift parameter for user k by using following optimization,

$$\max_{\phi_k, B_k^{ro}} \left\| [fh_k^{ro}]_{B_k^{ro},:} \right\| \quad s.t \quad \left| B_k^{ro} \right| = \tau \qquad (5)$$

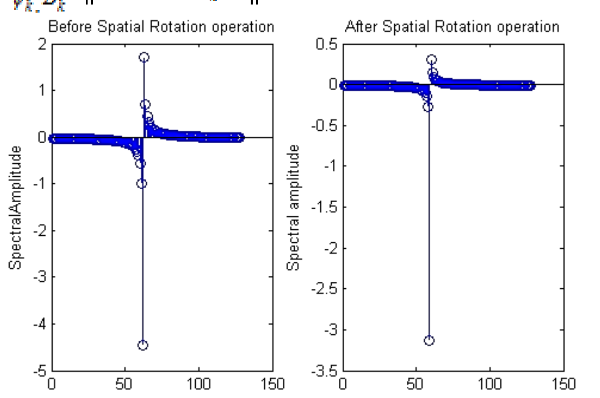

Fig.3 Comparison of single ray channels with/without spatial rotation

The preceding optimization can be achieved by sliding a window of size τ over the elements in fh_k^{ro} together by a 1-D search over $(\frac{-\pi}{M}, \frac{\pi}{M})$.

III. CHANNEL ESTIMATION WITH SBEM

A unified transmission strategy for a TDD/FDD massive MIMO system is introduced that utilizes the spatial signatures to realize orthogonal training and data transmission among different users. As shown in Fig.4, this framework always starts with preamble period. The preamble period is used to obtain the spatial signature of each user. After tracking spatial information of each user the users are grouped based on their spatial signature for further process.

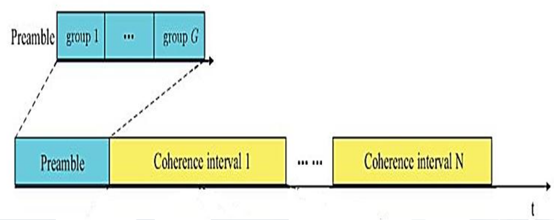

Fig.4 Communication Framework

Here we consider the users are present within a cell and τ (< K) orthogonal training sequences with length L (< T) are available and the corresponding orthogonal training set will be $S=[s_1,s_2,\ldots..s_\tau]$ € CLxτ with $S_i^H S_j = L\sigma_p^2\delta(i-j)$ where σ_p^2 is the signal training power.

Tracking of Spatial information through preamble Assume K=Gτ. Since we do not have any prior spatial information about users, we will have to divide the users into G groups each containing τ users such that τ orthogonal training sequences are enough for each group and conventional estimation methods are applied and length of the preamble is Gτ.

The received signals at the BS is given by,

$$Y = HD^{\frac{1}{2}}S^H + N = \sum_{i=1}^{G}\sum_{i=1}^{\tau}\sqrt{d_i}h_k s_i^H + N \qquad (6)$$

h_k can be estimated using Least Square as,

$$eh_k = \frac{1}{\sqrt{d_k}L\sigma_p^2}YS_k \qquad (7)$$

where, $H=[h_1,h_2,\ldots\ldots.h_\tau]$ € $C^{M\times\tau}$, $S=[s_1,s_2,\ldots..s_\tau]$ € $C^{L\times\tau}$ and $D=diag[d_1,\ldots\ldots d_\tau]$ and $d_k = \frac{P_k^{ut}}{\sigma_p^2}$ is used to satisfy the uplink training energy constraint for user-k, N is the additive white Gaussian noise. Repeating the similar operations in (7) for all G groups is used to obtain the

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estimates of all K users. The next step is to obtain the optimal shift parameter ϕ_k and spatial signature set of size τ for each user, as described in (5). The obtained channel information from preamble may only last for a short period for example one coherent time while it needs to be re estimated or tracked for later transmission. When a user and its surrounding obstacles does not change the position within the comparable time then no need to track the spatial information for few channel coherent times and only the accompanied $[fh_k^{ro}]_{B_k^{ro},:}$ should be re estimated. The Non-overlapping properties of different spatial signatures are used to overcome the insufficient problem of orthogonal training sequences. After obtaining of spatial signature of each user we may schedule them using Non-overlapping property of spatial signatures and also throughput is considered to improve the performance of each group.

IV. DATA TRANSMISSION WITH USER SECHEDULING

A greedy user scheduling algorithm is considered where the strongest channel gain first join the empty group and then other users with non-overlapping spatial signatures can join the same group only if the achievable sum rate increases afterwards.

User scheduling Algorithm

STEP-1:Calculate the Euclidean norm of the estimated channel vectors, i.e., $\left\| [fh_k^{ro}]_{B_k^{ro},:} \right\|$ for all users.

STEP-2: Initialize g=1, P=0, U_g^{dd} = NULL, $R(U_g^{dd}|P)=0$ and the remaining user set $U_r=\{1,\ldots\ldots.K\}$.

STEP-3: For the g[th] group, select the user with the maximum norm of channel in user set $l' = \arg\max_{l\in U_r} \|eh_l\|$ and remove the user from user set and add the user in U_g^{dd}.

STEP-4: Select all users U_r whose spatial signatures are Non-overlapping with users in U_g^{dd} and denote them by, U_g'. For Eg.,

$$u'_g = \{m \varepsilon u_r \left| B_m^{ro} \cap B_l^{ro} \right| = \phi, \forall l \in U_g^{dd}\}$$

STEP-5: If $U_g \neq \phi$ set P'=P+ρ and find a user m' in U_g' such that

$$m' = \arg\max_{m\in U_g} R(U_g^{dd} \cup \{m\}|P')$$

If $R(U_g^{dd} \cup \{m\} | P') \geq R(U_g^{dd} | P)$, set $U_g^{dd} = U_g^{dd} \cup \{m'\}$, $P = P'$, $U_r = U_r \setminus \{m'\}$ and go to step 4;Else go to step 6.

STEP-6: Store U_g^{dd} and $R(U_g^{dd}|P)$.If $U_r \neq \phi$,let g=g+1, go to step 3; Else, go to Step 7.

STEP-7: When the algorithm is stopped, the minimum number of user group G^{dd} is set as the current g, and the optimal user scheduling result is accordingly given by $U_1,\ldots\ldots U_G^{dd}$

To maximize the Throughput of each group the following constraint is adopted.

$$\max_{\{\rho_k\}} R(U_g^{dd} | P) = \sum_{k\in U_g^{dd}} \log_2(1+\gamma_k) \qquad (8)$$

$$s.t \sum_{k\in U_g^{dd}} \rho_k \leq P$$

where, γ_k is the Equivalent Signal to Noise ratio, P is the total power constraint of each group. It will vary dynamically based on no of users in that group.

γ_k can be represented as,

$$\gamma_k = \frac{\rho_k \left\| [h_k^{ro}]_{B_k^{ro},:} \right\|^2}{1 + \sum_{l\in K_g} (\rho_l \left| \Delta h_k^H h_l \right|^2 / \|h_l\|^2} \qquad (9)$$

This optimization problem can be solved by Water filling algorithm [6].

V. SIMULATIONS

In this section the effectiveness of the proposed strategy is demonstrated using numerical examples. We select M=128, K=32,d=λ/2. The channel vectors of different users are formulated using (1) and we consider Pr=100, fd=200 Hz and Ts=1μs and α_{kp} is randomly taken from CN(0,1) for all rays and all users, θ_{kp} is distributed inside $[\theta_k - \Delta\theta_k, \theta_k + \Delta\theta_k]$. And AS = 2 degree for all users. The system coherence interval is set as T=128 and τ =16. The length of the pilot symbol should satisfy 16≤L≤128. L may be 16, 32 and 64. The signal to noise ratio defined as, $\rho = \frac{\sigma_p^2}{\sigma_n^2}$. The channel estimation performance metric in terms Mean square error(MSE) is represented as

$$MSE = \frac{1}{K} \sum_{k=1}^{K} \frac{\|h_k - eh_k\|^2}{\|h_k\|^2}$$

Fig.5 shows comparison of MSE performances with different L values. It is observed that when L increases the MSE decreases. The total power for uplink training considered is $P_k^{ut} = L\rho$ for all users.

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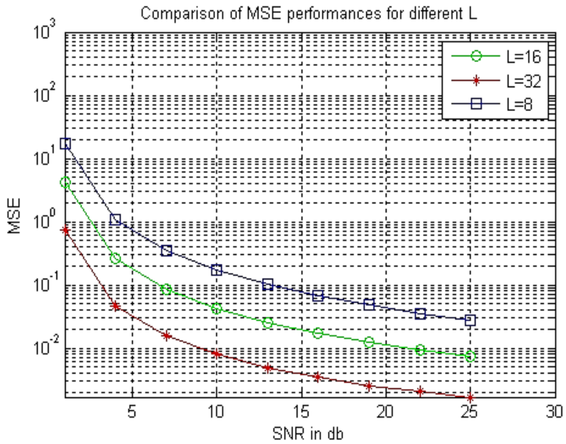

Fig.5 MSE performances for different L values

Fig.6 explains about MSE performance improvement with and without spatial rotation operation.

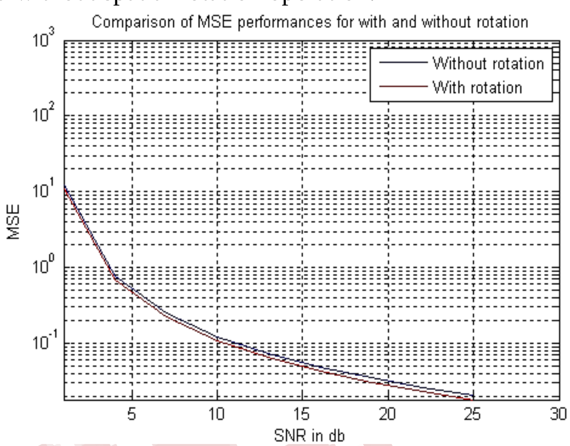

Fig.6 MSE performances for with and without spatial rotation

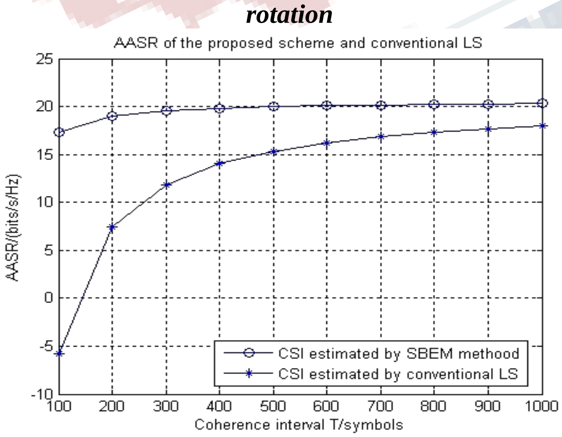

Fig.7 AASR of the proposed scheme and conventional LS From Fig.7, it is observed that the AASR of proposed SBEM is providing better performance than conventional Least square (LS) method.

VI. CONCLUSIONS

In this paper we exploited the characteristics of ULA and proposed a simple DFT based ST-BEM to represent the channel vectors with reduced parameters which helps to reduce the pilot overhead and feedback cost. The Uplink spatial signatures can be used for Downlink also based on the property angle reciprocity. This method applicable for both TDD/FDD massive-MIMO systems. Various numerical results are provided to demonstrate the effectiveness of the proposed approach.

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