Wireless Synchronization and Interference Alignment with Limited Interferer for Distributed Large Scale Multi User MIMO

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***Abstract*— Large Scale (Massive) MIMO enhances the advantages of the conventional MIMO in terms of data rate, energy efficiency and reliability. To increase the scalability of conventional massive MIMO, the distributed large scale MIMO is recommended. Synchronization for distributed large scale MIMO is needed due to the lack of common clock source to synchronize the transmitters. Limited Inter-User Connected Interference Alignment for K-User is proposed for Large Scale MU-MIMO precoding scheme. Moreover, we discuss phase rotation factor estimation and compensation to synchronize the distributed large scale MIMO. The Interference Alignment algorithm with antenna selection also employed to show the effect of the synchronization in distributed large scale MIMO performance.**

Keywords—synchronization; Interference Alignment, distributed large scale MIMO (key words)

I. Introduction

Mobile communication has been recently driven to abundant mobile data traffic generated by mobile video streaming and mobile internet usage. The wireless industry's main challenge is to provide higher data rates as well as to ensure the quality of services. The most prevalent solution to cope the scarce of wireless spectrums and resources due to the stated condition is the network densification. There are two approach that recently fascinated the research attention to achieve it, i.e. network MIMO [1,2] and massive MIMO [3-6]. The first solution is based on multicells with spatial separation deployed and coordinated to serve some user equipment and used to improve coverage and area spectral efficiency. The second approach using a great number of antenna at the base station to serve user equipment on the same time-frequency resources. Massive MIMO acquire all the benefits of MIMO (high data rate, reliability, energy efficiency, low interference)in a much greater scale[3] but deliver some drawbacks , i.e. limited coverage for highly spread user and low scalability. Network scheme, in contrast, attain higher coverage and scalability with expense in experiencing user interference and having a highly heterogeneous network topology where it is difficult to control, synchronize and coordinate.

To achieve better scalability and coverage for large scale MIMO, distributed massive MIMO is the possible solution. A large number of Access Point (AP) work as a distributed multi-antenna system. Moreover, by increase the number of antennas, Inter Carrier Interference (ICI) can be effectively mitigate [7].

Interference Alignment (IA) is one of precoding schemes that can be used in Multi User MIMO system in Interference Channel. However, the scaling of IA system to a large number of user is limited by a finite number of user with a fixed number of antenna, because of the restricted number of degrees of freedom from the spatial dimension at the transmitter and at the receiver [13]. [14] shows that degree of freedom scales unbounded with number of user and IA system can be scaled to K-user MIMO with the case of finite number interferer lower than the number of user. The literature used the iterative algorithm from [15].

In this paper we proposed the non-iterative K-User Interference Alignment with limited interferer to achieve higher scalability of IA system to the large number of user.

The other problem for the distributed massive MIMO compare to the classic (centralized) massive MIMO is the lack of the common clock source to synchronize the transmitters, since each transmitters has its own individual clock. Without the synchronization process, additional interference factors will be introduced and decrease the performance of the precoding process in the MIMO system.

Synchronization for multiple transmitters for distributed large scale MIMO has barely been discussed in the existing literature. Some works have been done for MISO and distributed Multi User (MU) MIMO, such as Software Defined Radio implementation for synchronization for 2 transmitter and 1 receiver MISO [8, 9], and SDR implementation of over the air synchronization for Multi User MIMO [10]. [11] investigates synchronization protocol for 4x4 distributed MIMO by coordinating Access Points by some of anchor APs and conclude that the scheme can be extend into a large distributed cooperative antenna system.

In this paper we also present wireless synchronization for multiple transmitters in 32x32 large scale and propose . Costas Loop as [8] is employed in large scale MIMO system to compensate phase rotation factor due to frequency offset experienced by independent clock in each transmitters. The compensated signal is precoded by proposed Interference Alignment Algorithm. We observe the Bit Error Rate of the unsynchronized and synchronized system to see the effect of frequency offset and synchronization process.

II. SYSTEM MODEL

Consider the large scale N_t x N_r MIMO single carrier system. A Master node is set to the system, dedicated to synchronize all transmitters in a form of local master-slave arrangement. The master node transmit a reference unmodulated signal to the transmitters act as Slave nodes. The reference signal is used by the transmitters in order to estimate the frequency shift between the Slave node and the Master node.

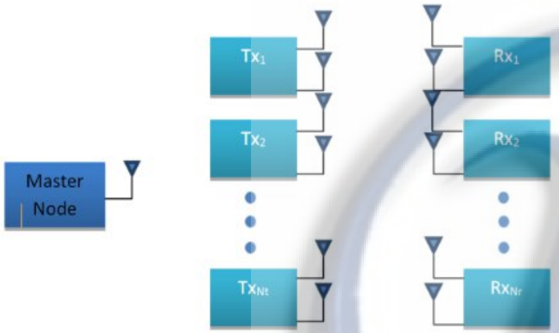

Fig. 1. Distributed MU MIMO System

Before transmitting to the receiver, the transmitter carry out the synchronization process using Costas Loop [8] that aimed for large scale MIMO system in this system. The transmitters will eventually communicate with the desired receiver using proposed Interference Alignment algorithm and the antenna selection discussed in [16].

III. DISTRIBUTED SYNCHRONIZATION

A. *Frequency Offset in Large Scale MIMO*

The baseband transmit signal is modulated with carrier frequency f_c and converted up to the passband signal then using a local carrier signal with expectantly the same carrier frequency at the slave nodes, it converted down to the baseband. During this process, the signal experiences distortion associated with carrier signal, i.e carrier frequency offset (CFO) caused by Doppler frequency shift.

The 1 x N_r complex baseband frequency domain signal at the j-th receiver after demodulation can be written as

$$\mathbf{y}_i = \sum_{i=1}^{N_t} \Theta_i \mathbf{H}_{ij} \Phi_j \mathbf{V}_j \mathbf{x}_j + \mathbf{z}_i \qquad (1)$$

where H_{ij} is the N_r x N_t channel matrix between j-th transmitter and i-th receiver, x_j is $N_s\,x\,1$ vector of data symbol transmitted from j-th transmitter simultaneously, V_j is the N_t x N_s interference alignment precoding matrix for user i. Θ and Φ are some deterministic multiplicative phase rotation terms that combine the carrier frequency offset, sampling frequency offset and time offset [11]. Θ is N_r x N_r diagonal matrix that can be compensated at each receiver by some established synchronization methods [17]. However, Φ presents between the precoded transmit vectors and must be compensated at transmitter since it decrease the precoding performance during the transmission process [11].

Φ[m,n] is N_t x N_t diagonal matrix given as

$$\Phi = \begin{bmatrix} e^{2\pi\left[\frac{n}{N}\right]\delta_1 m} e^{2\pi\Delta_1 m} & 0 & 0 & 0 \\ 0 & e^{2\pi\left[\frac{n}{N}\right]\delta_2 m} e^{2\pi\Delta_2 m} & 0 & 0 \\ . & . & . & . \\ 0 & 0 & . & e^{2\pi\left[\frac{n}{N}\right]\delta_{N_t} m} e^{2\pi\Delta_{N_t} m} \end{bmatrix}$$

(2)

where n is subcarrier index, N = block length. m is block index, δ_i and Δ_i is i-th transmitter SFO and CFO respectively that defined as [11]

$$\delta_i \underline{\underline{\Delta}} (N+L) T_S \varepsilon_i \;,\; \Delta_i \underline{\underline{\Delta}} \kappa \delta_i \qquad (3)$$

where L is CP length, T_s is sampling time, k is constant factor that defined as f_c /f_s . f_c and f_s is carrier and sampling frequency respectively. ε_t is i.i.d across the receivers an uniformly distributes over [-ε_{max}, ε_{max}], with ε_{max} =800Hz (20 ppm frequency error).

The time offset between transmitters is assumed to be within the length of cyclic prefix, therefore time offset is neglected since it will be compensated as a part of channel estimation process from pilots data. We also assume perfect phase synchronization for the considered system.

B. *Frequency Offset Estimation in Large Scale MIMO using Costas Loop*

As discused in section 1, in distributed MIMO, the carrier and sampling frequency offset must be compensated by a synchronization process in order for IA precoding to work out. To overcome the effect of the unsynchronized transmitters, we estimate the frequency shift experienced by each transmitters using Costas Loop and then compensate the transmitted time domain symbol by multiplying it with the estimated frequency shift.

To estimate the frequency offset experienced by each transmitter using Costas loop, we need one Master node dedicated to send reference signal to transmitters roled as slave nodes.

The reference baseband signal sent from master node to the transmitters (slave nodes) is given as [18]:

$$m(t) = \sin 2\pi 150\, t / f_s \tag{4}$$

where f_s is sampling frequency of master node. The carrier signal of master node is

$$c = \cos 2\pi f_c t / f_s \tag{5}$$

where f_c is carrier frequency of master node.

The modulated reference signal from master node is sent to the slave node (transmitters) and is inputted to the Costas loop block and used to calculate the frequency offset between master node and slave nodes. Costas loop input signal experience frequency offset due to the master node oscillator and slave nodes local oscillator frequency difference. The input signal at Costas loop in i-th transmitter is given as [18]:

$$s_i(t) = m(t)\cos(2\pi f_c t / f_s + \phi_i) \tag{6}$$

where φ_i is the phase r between the i-th local carrier and master carrier.

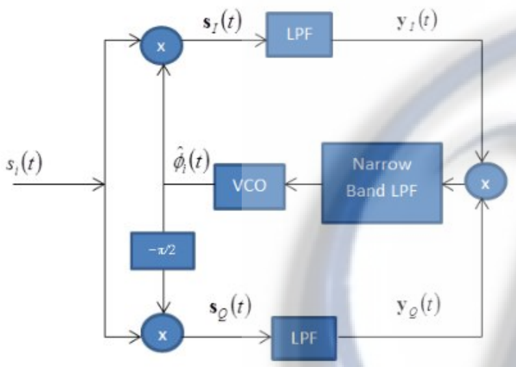

Fig. 2. Costas Loop

Figure 2 shows that the input signal then multiplied with I-channel and Q-channel signal generated by every local oscillator of transmitters (slave nodes) and can be written as vector $\mathbf{s}_I$ and $\mathbf{s}_Q$:

$$\mathbf{s}_I = \begin{bmatrix} s_{I_1}(t) \\ s_{I_2}(t) \\ \vdots \\ s_{I_{N_t}}(t) \end{bmatrix} = \begin{bmatrix} s_1(t)\cos(2\pi f_c t / f_s + \hat{\phi}_1) \\ s_2(t)\cos(2\pi f_c t / f_s + \hat{\phi}_2) \\ \vdots \\ s_{N_t}(t)\cos(2\pi f_c t / f_s + \hat{\phi}_{N_t}) \end{bmatrix} \tag{7}$$

$$\mathbf{s}_Q = \begin{bmatrix} s_{Q_1}(t) \\ s_{Q_2}(t) \\ \vdots \\ s_{Q_{N_t}}(t) \end{bmatrix} = \begin{bmatrix} s_1(t)\sin(2\pi f_c t / f_s + \hat{\phi}_1) \\ s_2(t)\sin(2\pi f_c t / f_s + \hat{\phi}_2) \\ \vdots \\ s_{N_t}(t)\sin(2\pi f_c t / f_s + \hat{\phi}_{N_t}) \end{bmatrix} \tag{8}$$

Multiplied I-channel and Q-channel signal is integrated and accumulated in LPF and generate :

$$\mathbf{y}_Q = \begin{bmatrix} y_{Q_1}(t) \\ y_{Q_2}(t) \\ \vdots \\ y_{Q_{N_t}}(t) \end{bmatrix} = \begin{bmatrix} \int_0^T s_{Q_1}(t)dt \\ \int_0^T s_{Q_2}(t)dt \\ \vdots \\ \int_0^T s_{Q_{N_t}}(t)dt \end{bmatrix} \tag{9}$$

Phase difference between the i-th local carrier and the input modulated signal then estimated by Narrow band LPF and VCO process written as :

$$\hat{\phi}_i(t) = K_{VCO} \int_{-\infty}^{t} y_{Q_i}(t) y_{I_i}(t) dt \tag{10}$$

where K_{VCO} is the sensitivity of VCO.

C. Synchronization in Large Scale MIMO

In order to compensate the phase different, the transmitted frequency domain data ($\mathbf{x}_i$) must be multiplied by phy estimated phase rotation factor in (10).

$$\begin{pmatrix} \tilde{x}_1 \\ \tilde{x}_2 \\ \cdot \\ \tilde{x}_{N_{Tx}} \end{pmatrix} = \begin{pmatrix} e^{-j2\pi\hat{\varphi}_1} & 0 & \cdot & 0 \\ 0 & e^{-j2\pi\hat{\varphi}_2} & \cdot & 0 \\ \cdot & \cdot & \cdot & \cdot \\ 0 & 0 & \cdot & e^{-j2\pi\hat{\varphi}_{N_{Tx}}} \end{pmatrix} \begin{pmatrix} x_1 \\ x_2 \\ \cdot \\ x_{N_{Tx}} \end{pmatrix} \tag{11}$$

where $\hat{\varphi}_i = fft(\hat{\phi}_i)$.

The phase rotation factor applied for each transmitter will eliminate the effect of ϕ in equation (1).

D. Interference Alignment with Limited Interferer in Large Scale MIMO

In this section we introduce the limited interferer Interference Alignment for K-User MIMO. This scenario originates from the cellular network phenomenon, where the far-away interference signal power is highly decrease due to the distance between the non-adjacent users.

Each receiver receives only from a limited subset of the K transmitters. We choose the number of interferer based on the equation of degree of freedom.

$$d \le \frac{2N}{L+1} \tag{12}$$

where d= degree of freedom, N = Number of antenna per user and L= number of interferer. For N = 1 and d =1, we get L= 3.

The limited interferer Interference Alignment algorithm is adapted from [12]. The upper bond of the precoding equation for 1th transmitter is modified from the number of user index

(K) to the number of interferer (L), as shown in equation 13. The sets of column vectors of 1th transmitter precoding ($\mathbf{V}_1$)is equal to the sets $\overline{V}_1$ where

$$\overline{V}_1 = \left\{ \left(\prod_{m,l} \left(\mathbf{T}_l^{[m]}\right)^{\alpha_{mk}} \right) \mathbf{w} : \forall \alpha_{m,k} \in \{0,1,2..,n\} \right\} \tag{13}$$

where $m,l \in \{2,3,..,L\}, m \neq l, (m,k) \neq (2,3)$

$$\mathbf{T}_j^{[i]} = (\mathbf{H}_{i1})^{-1} \mathbf{H}_{ij} \mathbf{S}_j \tag{14}$$

$$\mathbf{S}_j = (\mathbf{H}_{i1})^{-1} \mathbf{H}_{13} (\mathbf{H}_{23})^{-1} \mathbf{H}_{21} \tag{15}$$

For $L = 3$, $\mathbf{V}_1$ is written as

$$\mathbf{V}_1 = eign\left(\mathbf{H}_{31}^{-1}\mathbf{H}_{32}\mathbf{H}_{12}^{-1}\mathbf{H}_{13}\mathbf{H}_{23}^{-1}\mathbf{H}_{21}\right) \tag{16}$$

The channel (**H**) is assumed to be perfectly known in each receiver node and is also used to calculate the j-th transmitter precoding matrix $\mathbf{V}_j$. For simplification, we only consider the process for 1-th receiver below:

$$\mathbf{V}_j = \mathbf{S}_j \mathbf{B} \quad j = 2,3,4..., N_t \tag{17}$$

where $\mathbf{B} = (\mathbf{H}_{21})^{-1} \mathbf{H}_{23} \mathbf{V}_3$

IV. SIMULATION RESULTS

We aim to observe the performance of the Interference Alignment algorithm based on limited interferer and the effect of phase offset compensation by wireless Costas Loop synchronization in large scale Distributed MIMO system . We simulate two scenario 16 and 32 users with two antennas for every user. QPSK modulation is used in this simulation. One dedicated Master node to send reference signal to transmitters and perform Costas loop to estimate the offsets of each transmitters and then compensate it.

Figure 3 and 4 shows the BER performance of a 32 x 32 and 16 x 16 Distributed MU MIMO with proposed IA algorithm respectively. The simulation results show that at SNR 30dB the proposed algorithm achieves BER performance in order of 10^{-2} for 16 x 16 and 10^{-1} for 32 x 32 Distributed MU MIMO. We can also observe that BER performance of the system decrease for larger number of user. The performance for the larger scale MU MIMO decrease along with the increasing of total offset experienced by all transmitters. In terms of the synchronization effect, the simulation results show that there is performance improvement after implementing synchronization in the system. We observe the BER performance difference after synchronization is 20dB for 16 user MIMO and 25 dB for 32 user MIMO at BER = 10^{-1}.

TABLE I. BER PERFORMANCE DIFFERENCE AFTER SYNC

Number of User	BER Performance Difference (dB)
16	20 dB
32	25 dB

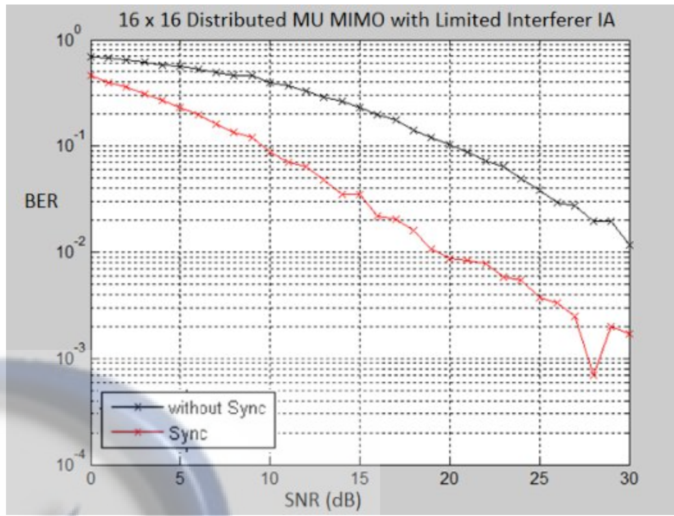

Fig. 3. BER performance of 16 x16 Distributed MU MIMO with Limited Interferer IA

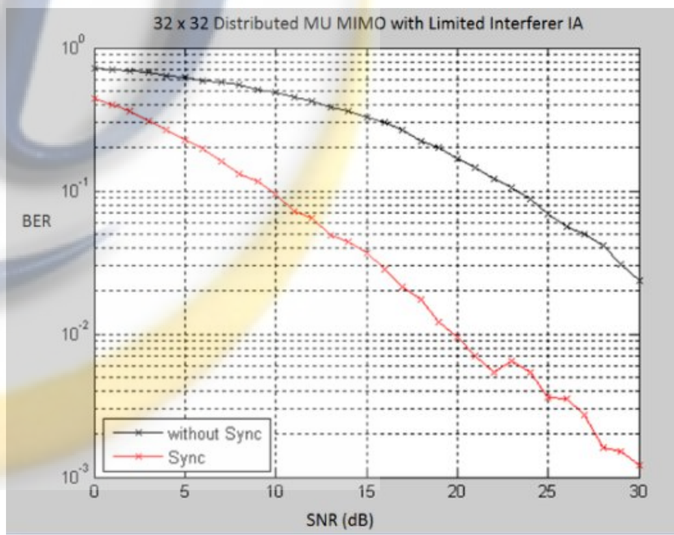

Fig.4. BER performance of 32 x 32 Distributed MU MIMO with Limited Interferer IA

V. CONCLUSION

In this paper Interference Alignment algorithm with limited interference considered during the precoding vector calculation is proposed. Moreover we employ wireless synchronization based on Costas loop to synchronize the transmitter in the large scale MIMO system with proposed Interference Alignment algorithm. The simulation result showed that the large MIMO system with limited interferer IA algorithm achieve reasonable BER performance.

A comparison of BER performance before and after synchronization process is presented. The result show that wireless synchronization based on Costas Loop increase the performance of distributed MIMO system with proposed IA algorithm. The performance increment is greater for the larger scale distributed MIMO system.

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