Time Domain Correlation Based Joint Channel Estimation for Multi-Cell Cooperative OFDM Networks

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Abstract**—**In this paper, we focus on joint channel estimation (JCE) of multi-cell networks, which is the basis for application of multi-cell cooperative. For overcoming the weakness that the existing multi-cell JCEs need power delay profile (PDP) knowledge of all multiple cells remained the same and known by receiver or pilot sequence sets of all cells being identical and other limitations, the paper presents a time domain correlation based JCE algorithm for multi-cell cooperative network when PDPs of multiple cells are not same and unknown and derives the corresponding Cramer-Rao bound (CRB). Then, by using Generalized Akaike Information Criterion (GAIC) to estimate PDPs of all cells for reducing the signal space of channel estimation, the paper further optimizes this JCE algorithm. Simulation results illustrate the proposed algorithms have good mean square error (MSE) performance, and corresponding space frequency block coded (SFBC) cooperative multi-cell transmission system have the good bit error rate (BER) performance too.

Index Terms**—**Multi-cell cooperation, Joint channel estimation, Time domain correlation, Cramer-Rao Bound, GAIC

I. Introduction

Nowadays, growing demands of wireless communications for higher throughputs and spectral efficiencies has promoted the development of Orthogonal Frequency Division Multiplexing (OFDM) based beyond 3th generation (B3G) or 4th generation (4G) networks. Supporting frequency reuse of one or close to one is a key characteristic of OFDM B3G/4G networks. But it will lead to more serious inter-cell interference (ICI) problem [1]. In order to mitigate or eliminate the impacts of ICI, strategy of multi-cell cooperation and joint process has recently attracted more attentions [2]. Main idea of it is that the base stations (BS) in multiple cells are connected via a high-speed backhaul link which allows information or data streams to be reliably exchanged among them and jointly processed. While the multiple BSs behave like a single super-BS and ICI can be avoided or even exploited as useful signal and the system average performance will be improved. The emerging technologies based on multi-cell cooperation and joint process such as joint transmit, joint precoding, interference coordination or cancellation have been researched widely and got great progress in resisting ICI and improving performance of system. However, the employment of these key technologies is highly dependent on the whole exact channel state information (CSI) among the cooperative BSs and the users. Therefore, the optimum channel estimation is the base of future wireless communication network.

In conventional non-cooperative cellular systems, general method for channel estimation is to mitigate or eliminate ICI with estimation of interference characteristic of adjacent cells firstly and then to estimate channel information, the results are not satisfactory and have a high computational complexity. In cooperative cellular systems, joint channel estimation (JCE), which is initially applied in a multi-user scheme, could be extended to a multi-cell environment and obtained better system performance as depicted in publications [3]-[6] when pilot sets of multiple cells are known. Assuming that the power delay profiles (PDP) of all channels (in this paper, we exploit the concept of PDP to precisely represent multipath delays power and multipath tap location [7] and the below is same) do not overlap and the pilot sequences of all cells remain the same, Ref. [3] developed a JCE method for the desired and interference channels. In [4], a multi-cell JCE method proposed for TD-SCDMA downlink was proven successful in improving channel estimation accuracy and yields better system performance. Defined a new concept of multi-branch systems to refer to either multi-user and/or multi-antenna systems, Ref. [5] explained the relationship between time and frequency domain JCE in these systems. In [6], for enhancing the practical value of multi-cell JCE, the author further investigated on pilot design and presents two general optimal pilot sequences based on minimizing the MSE. However, the mentioned above multi-cell JCE algorithms need PDP knowledge of all multiple cells remained the same and known by receiver

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or pilot sequence sets of all cells being identical and other limitations. In general, the signals received from different BSs or different users will not have the same PDP for different spatial locations of these BSs or users [8] and while the PDP knowledge will not be known a priori to receiver. These problems make the practical value of multi-cell JCE reduced severely.

For overcoming the weakness of existing multi-cell JCE algorithms, the paper presents a time domain correlation based JCE algorithm for multi-cell cooperative network and derives the corresponding Cramer-Rao bound (CRB) when PDPs of multiple cells are not same and unknown. Then, by using Generalized Akaike Information Criterion (GAIC) to estimate PDPs of all cells for reducing the signal space of channel estimation, the paper further optimizes this JCE algorithm.

The rest of the paper is organized as follows: Section II introduces a cooperative multi-cell OFDM system model and describes the system expression in time domain. Section III presents a time domain correlation based multi-cell JCE algorithm and further optimizes it by exploiting GAIC. Numerical simulations are presented to verify performance of the proposed algorithms in section IV and the paper will be concluded in last Section V.

Notation: In this paper, Bold letters represent a matrix or a column vector; $\lceil x \rceil$ denotes the nearest integer larger than or equal to x; $(\cdot)^{\mathrm{T}}$, $(\cdot)^{*}$ and $(\cdot)^{\mathrm{H}}$ stand for the transpose, complex conjugate and complex conjugate transpose respectively; $(\cdot)_N$ represents modulo N operation; *det(x)* is the determinant of $\mathbf{x}$; $Re(x)$ and $Im(x)$ indicate real part and imaginary part of x; I_N denotes $N \times N$ identity matrix; $\|\cdot\|$ denotes the Euclidean norm; $tr[\cdot]$ and $E[\cdot]$ represent trace and expectation respectively.

II. System Models

We consider an OFDM system operating with a bandwidth of $Bw = 1/T$ Hz (T is the sampling period). The system consists a total of N subcarriers, using the QPSK modulation for communicating over frequency selective Rayleigh fading channels. In order to eliminate inter-symbol interference (ISI), a cyclic prefix (CP) of length L_{CP} is inserted before each symbol. Comb-type pilot pattern is exploited to perform channel estimation, i.e., in each OFDM symbol, N_p tones used as pilots to assist channel estimation are evenly distributed over N subcarriers with equal power. After an inverse discrete fast Fourier transform (IFFT) operation, the time domain transmitted signals can be expressed as [9]:

$$\begin{aligned} s(n) &= IFFT_N(S(k)) \\ &= IFFT_N(P(k)) + IFFT_N(D(k)) \\ &= p(n) + d(n) \end{aligned} \tag{1}$$

where $k = 0,1,\mathrm{L},N-1$ and $n = 0,1,\mathrm{L},N-1$ denote the frequency domain subcarrier index and time domain sample index of an OFDM symbol, $IFFT_N(\times)$ indicates N-point IFFT transform. $S(k)$ is the frequency domain transmit signal. $P(k)$ and $D(k)$ represent the pilot subcarriers set and data subcarriers set of $S(k)$, while $p(n)$ and $d(n)$ are the corresponding time domain signals of $P(k)$ and $D(k)$ respectively.

Assuming that the channel impulse response at time t has L multipath components, in which each path is characterized by a complex gain factor $h_l(t)$ and a corresponding delay $\tau_l(t)$ and has the form:

$$h(t,\tau) = \sum_{l=0}^{L-1} h_l(t)\delta(\tau - \tau_l(t)\cdot T) \tag{2}$$

where $\tau_l(t)$ represents the l-th path's sampling delay at time t and normalized by T, of which the maximum sampling delay value is denoted as W. $h_l(t)$ is zero-mean complex Gaussian random processes with $E[h_l(t)h_l^*(t)] = \sigma_l^2$ and $E[h_l(t)h_k^*(t)] = 0$ for any $k \neq m$. σ_l^2 is the power of the l-th path. Additionally, we assume the power of channel is normalized, i.e. $\sum_{l=0}^{L-1}\sigma_l^2 = 1$.

Considering PDP of channel is constant over an OFDM symbol duration, CP length is efficient larger than W and assuming perfect synchronization in multiple cells, after CP removal at receiver, the discrete-time signal can be shown as

$$\begin{aligned} r(n) &= s(n) \otimes h(n) + w(n) \\ &= d(n) \otimes h(n) + p(n) \otimes h(n) + w(n) \end{aligned} \tag{3}$$

where $\otimes$ stands for the circular convolution operator, $w(n)$ is a statistically independent and identically distributed (i.i.d) complex Gaussian noise with zero mean and variance σ_w^2.

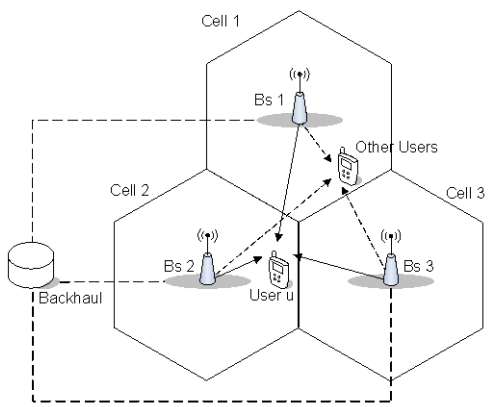

Figure 1. An OFDM multi-cell cooperation scenario with frequency reuse 1.

Consider an application scenario of Multi-cell cooperative OFDM network downlink with frequency reuse 1 is illustrated as an example in Fig. 1. N_{Bs} BSs each equipped with N_T transmit antennas cooperatively transmit to U users distributed around N_{Bs} cells. Based on cooperation, pilot set of multiple cells is known by

every user and exploited to estimate corresponding CSI, while all BSs could share the information. Therefore, joint process techniques can be applied to further improve system performance.

For simplicity, we discuss channel estimation for case of only one user, because, from signal processing point of view, multiple antenna wireless channels and multi-user wireless channels have no intrinsical difference, if the channels are assumed to be independent from each other, both can be reduced to a Multiple-Input and Single Output (MISO) channel model [5]. So the system diagram is depicted as Fig. 2.

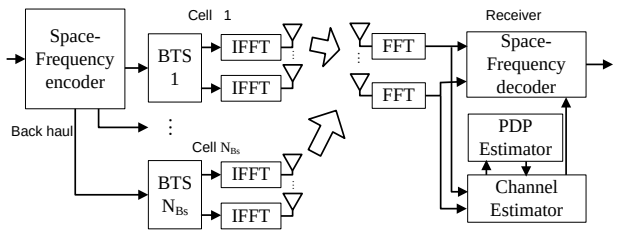

Figure 2. Time domain correlation based JCE model for multi-cell cooperation system.

Due to the difference on location for multiple cells, the PDPs of these cells are not same [8]. Then, set channel order as L, we describe this condition that PDPs of different cells are not same with the maximum time delay set $W=\{W_1,W_2,\text{L},W_{N_{Bs}}\}$ and call for CP length being larger than the maximum value of W, i.e., $L_{CP}\geq\max\{W_i\}$, $i=1,2,\text{L},N_{Bs}$. Assuming perfect synchronization in multiple cells, the time domain received signal vector of the q-th receive antenna of user u can be then expressed as:

$$\begin{aligned} r_u^q(n) &= \sum_{i=1}^{N_{Bs}}\sum_{j=1}^{N_T} s_{u,j,i}(n)\otimes h_{u,j,i}^q(n)+w_u^q(n) \\ &= \sum_{i=`}^{N_{Bs}}\sum_{j=1}^{N_T}\sum_{l=0}^{L'-1} h_{u,j,i}^q(l)p_{u,j,i}((n-l)_N) \\ &+\sum_{i=`}^{N_{Bs}}\sum_{j=1}^{N_T}\sum_{l=0}^{L'-1} h_{u,j,i}^q(l)d_{u,j,i}((n-l)_N)+w_u^q(n) \end{aligned} \tag{4}$$

where $n=0,1,\text{L},N-1$, $s_{u,j,i}(n)$ is the transmitted signal from the cooperative multiple cells to user u. $h_{u,j,i}^q(n)$ denotes the time domain CIR sample between the j-th transmit antenna of i-th BS and the q-th receive antenna of user u. For convenience, ignoring the indexes u and q, (4) becomes

$$\begin{aligned} r(n) &= \sum_{i=1}^{N_{Bs}}\sum_{j=1}^{N_T}\sum_{l=0}^{L'-1} h_{j,i}(l)(p_{j,i}((n-l)_N) \\ &+d_{j,i}((n-l)_N))+w(n) \end{aligned} \tag{5}$$

Rewriting (5) in matrix form as

$$\begin{aligned} r &= \sum_{i=1}^{N_{Bs}}\sum_{j=1}^{N_T} s_{j,i}h_{j,i}+w \\ &= sh+w = ph+dh+w \end{aligned} \tag{6}$$

where $\mathbf{s}_{j,i}$ is a $N\times L'$-dimension circulant matrix with its first column being the vector $\mathbf{s}_{j,i}=[s_{j,i}(0),\text{L},s_{j,i}(N-1)]^{\text{T}}$, $\mathbf{h}_{j,i}=[h_{j,i}(0),\text{L},h_{j,i}(L'-1)]^{\text{T}}$ is a L'-dimension vector. $\mathbf{s}=[\mathbf{s}_{1,1},\text{L},\mathbf{s}_{N_T,1},\text{L},\mathbf{s}_{1,N_{Bs}},\text{L},\mathbf{s}_{N_T,N_{Bs}}]$ represents the time domain transmitted signal matrix with dimension of $N\times N_{Bs}N_TL'$ and $\mathbf{h}=[\mathbf{h}_{1,1},\text{L},\mathbf{h}_{N_T,1},\text{L},\mathbf{h}_{1,N_{Bs}},\text{L},\mathbf{h}_{N_T,N_{Bs}}]^{\text{T}}$ indicates the channel matrix of cooperative multiple cells with dimension of $N_{Bs}N_TL'\times 1$. Since the matrix $\boldsymbol{p}$ and $\boldsymbol{d}$ have the same structure as $\mathbf{s}$, they need not repeat here.

III. Time Domain Correlation Based Joint Channel Estimaion

Obviously, $\mathbf{s}$ in (6) is an ill-conditioned matrix. And according to least squared (LS) criteria, there is no certain solution of $\boldsymbol{h}$. We can solve this problem with a method of special pilot design.

A. Pilots Design

According to (1), the time domain transmitted signal of multiple cells can be expressed as

$$\begin{aligned} s_{j,i}(n) &= IFFT_N(S_{j,i}(k)) \\ &= IFFT_N(P_{j,i}(k))+IFFT_N(D_{j,i}(k)) \end{aligned} \tag{7}$$

where $S_{j,i}(k)$ is the OFDM frequency domain transmitted symbol from the j-th transmit antenna of i-th BS. $P_{j,i}(k)$ and $D_{j,i}(k)$ represent the pilot subcarriers set and data subcarriers set of $S_{j,i}(k)$, which can be expressed respectively as [10]:

$$P_{j,i}(k)=\begin{cases} S_{j,i}(k), & k\in P \\ 0, & k\notin P \end{cases}=\begin{cases} S_{p;j,i}(m), & k=(m-1)D_f \\ 0, & k=others \end{cases} \tag{8}$$

$$D_{j,i}(k)=\begin{cases} 0, & k\in P \\ S_{j,i}(k), & k\notin P \end{cases}=\begin{cases} 0, & k=(m-1)D_f \\ S_{d;j,i}(m'), & k=others \end{cases} \tag{9}$$

here $m=1,2,\text{L},N_p$, $m'=1,2,\text{L},N-N_p$. $S_{p;j,i}(m)$ and $S_{d;j,i}(m)$ are the corresponding pilot sequence and data sequence. $P=\{0,D_f,\text{L},(N_p-1)D_f\}$ indicates the subcarrier index of pilot and $D_f=N/N_p$ indicates the distance between two adjacent pilots.

We exploit Chu sequence to design pilots which has perfect orthogonality as [11]. Letting $\Delta=\lceil N_p/(N_T\cdot N_{Bs})\rceil$, the pilot value $S_{p;j,i}(m)$ sent from the j-th transmit antenna of i-th BS of length N_p can be described as

$$\begin{aligned} S_{p;j,i}(m) &= S_{j,i}(k_m) \\ &= \frac{A}{\sqrt{N_T}}\left[\frac{1}{\sqrt{N_p}}C(m)\right]e^{j\frac{2\pi m\cdot\Delta((i-1)N_T+(j-1))}{N_p}} \\ &= \frac{A}{\sqrt{N_T}}\left[\frac{1}{\sqrt{N_p}}\sum_{n=0}^{N_p-1}c(n)e^{-j\frac{2\pi mn}{N_p}}\right]e^{j\frac{2\pi m\cdot\Delta((i-1)N_T+(j-1))}{N_p}} \end{aligned} \tag{10}$$

where $i=1,2,\text{L},N_{Bs}$, $j=1,2,\text{L},N_T$ and $k_m=(m-1)D_f$, $m=1,2,\text{L},N_p$. $A=\sqrt{E_p}$ represents the amplitude of the

pilot symbol when considering both pilot subcarriers and data subcarriers of the system with equal power E_p, $c(n)$ denotes a Chu sequence of length N_p as the basis sequence for pilot design and $C(m)$ stands for the Fourier transform of $c(n)$. Hence, $c(n)$ can be expressed as:

$$c(n)=\begin{cases} e^{j(\pi r n^2)/N_p}, & \text{for even } N_p \\ e^{j(\pi r(n-1)n)/N_p}, & \text{for odd } N_p \end{cases},\quad n=1,2,\mathrm{L},N_p \tag{11}$$

in which r and N_p are relatively prime. While it has the following good autocorrelation property:

$$\begin{aligned} R_{cc}(n) &= \sum_{l=0}^{N_p-1} c(l)c^*((l-n)_{N_p}) \\ &= N_p\delta(n), n=0,\cdots,N_p-1 \end{aligned} \tag{12}$$

It can be seen that $s_{j,i}(n)$ slips $((i-1)N_T+(j-1))\Delta$ sample length compared to $s_{1,1}(n)$ in time domain. The nature of pilot design above mentioned is that the pilot sequence of different transmit antenna and different BS is created by the same basis Chu sequence $c(n)$ with different shifting number of time domain samples, so the receiver can distinguish the useful signals of different transmit antenna and different BS from the received mixed signal to apply channel estimation.

B. Time Domain Correlation Based Joint Channel Estimation Algorithm

According to (5), by performing circular convolution between received time domain signal $r(n)$ and the basis sequence $c(n)$, we can obtain:

$$\begin{aligned} R_{rc}(l) &= \sum_{n=0}^{N-1} r(n)\cdot c^*((n-l)_{N_p}) \\ &= \sum_{n=1}^{N-1}\sum_{i=1}^{N_{Bs}}\sum_{j=1}^{N_T}\sum_{l'=0}^{L'-1} h_{j,i}(l')(p_{j,i}((n-l')_N) \\ &\quad + d_{j,i}((n-l')_N))\cdot c^*((n-l)_{N_p}) \\ &\quad + \sum_{n=1}^{N-1} w(n)\cdot c^*((n-l)_{N_p}) \\ &= \sum_{i=1}^{N_{Bs}}\sum_{j=1}^{N_T} R_{p;j,i}(l) + \sum_{i=1}^{N_{Bs}}\sum_{j=1}^{N_T} R_{d;j,i}(l) + R_w(l) \end{aligned} \tag{13}$$

Because of

$$p_{j,i}(l)=\frac{A}{\sqrt{N_T}\sqrt{D_f}}c(l+\Delta((i-1)N_T+(j-1)))_{N_p} \tag{14}$$

the $R_{p;j,i}(l)$ and the $R_{d;j,i}(l)$ in (13) can be derived as follow:

$$\begin{aligned} R_{p;j,i}(l) &= \sum_{n=0}^{N-1}\sum_{l'=0}^{L'-1} h_{j,i}(l')p_{j,i}((n-l')_N)c^*((n-l)_{N_p}) \\ &= \frac{AN}{\sqrt{D_f N_T}}\sum_{l'=0}^{L'-1} h_{j,i}(l')\delta\left[l-l'+\Delta((i-1)N_T+(j-1))\right]_{N_p} \end{aligned} \tag{15}$$

and

$$\begin{aligned} R_{d;j,i}(l) &= \sum_{n=0}^{N-1}\sum_{l'=0}^{L'-1} h_{j,i}(l')d_{j,i}((n-l')_N)\cdot c^*((n-l)_{N_p}) \\ &= \frac{\sqrt{D_f N_T}}{AN}\sum_{l'=0}^{L'-1} h_{j,i}(l')\sum_{n=0}^{N-1}\sum_{m=0}^{N-1}\Bigg[\sum_{k=0,k\neq m}^{N-1} D_{j,i}(m)P^*(k)\times \\ &\quad e^{j2\pi((m-k)n-ml'+kl)/N} + D_{j,i}(m)P^*(m)e^{j2\pi(-ml'+kl)/N}\Bigg] \end{aligned} \tag{16}$$

For reason of pilot and data subcarriers of an OFDM symbol occupying different subcarrier locations, we can get $D_{j,i}(m)P^*(m)=0$ and $\sum_{n=0}^{N-1} e^{j2\pi((m-k)n)/N}=0$. Therefore,

$$\begin{aligned} R_{d;j,i}(l) &= \frac{\sqrt{D_f N_T}}{AN}\sum_{l'=0}^{L'-1} h_{j,i}(l')\sum_{n=0}^{N-1}\sum_{\substack{k=0\\k\neq m}}^{N-1}\Big[D_{j,i}(m)\times \\ &\quad P^*(k)e^{j2\pi(-ml'+kl)/N}\sum_{m=0}^{N-1} e^{j2\pi((m-k)n)/N}\Big]=0 \end{aligned} \tag{17}$$

Hence, (13) can be rewritten as

$$\begin{aligned} R_{rc}(l) &= \sum_{i=1}^{N_{Bs}}\sum_{j=1}^{N_T}\frac{AN}{\sqrt{D_f N_T}}\sum_{l'=0}^{L'-1}\Big\{h_{j,i}(l')\times \\ &\quad \delta\left[l-l'+\Delta((i-1)N_T+(j-1))\right]_{N_p}\Big\} \\ &\quad + \sum_{n=0}^{N-1} w(n)c^*(n-l)_{N_p} \end{aligned} \tag{18}$$

where $l=0,1,\mathrm{L},N_p-1$ in equations from (13) to (18). Letting $L'=\Delta$, if the conditions of $L'\geq\max\{W_i\}$, $i=1,2,\mathrm{L},N_{Bs}$ and $L'<N_p$ can be met, the $L'\times 1$-dimension sub-channel estimator $\hat{h}_{j,i}$ between the j-th transmit antenna of i-th BS and the user can be derived as

$$\hat{h}_{j,i}(l')=\frac{\sqrt{D_f N_T}}{AN}R_{rc}(l'+((i-1)N_T+(j-1))\Delta) \tag{19}$$

where $l'=0,1,\mathrm{L},L'-1$.

Cramer-Rao Bound (CRB) reflects a lower bound on the error variance for an unbiased estimator[12]. Now we compute the CRB for estimator of $\boldsymbol{h}$ as below.

According to (6), $N\times 1$-dimension vector $\boldsymbol{w}$ are Gaussian distributed with zero-mean and covariance matrix $C=\sigma_w^2 I_{N_p}$. Accordingly,

$$r: CN(sh,C) \tag{20}$$

then $\mu(h)=sh=ph+dh$ and $C(h)=C=\sigma_w^2 I_{N\times N}$. Thus the Probability Density Function (PDF) of $\boldsymbol{r}$ conditioned on $\boldsymbol{h}$ is

$$\begin{aligned} p(r;h) &= \frac{1}{\pi^N det(C(h))}exp\left(-\frac{(r-\mu(h))^H(r-\mu(h))}{C(h)}\right) \\ &= \frac{1}{\pi^N det(C)}exp\left(-\frac{(r-(ph+dh))^H(r-(ph+dh))}{C}\right) \end{aligned} \tag{21}$$

Therefore, the fisher information matrix $I(h)_{k,l}$ is given by

$$[I(h)]_{k,l}=E\left[\frac{\partial lnp(r;h)}{\partial h(k)}\frac{\partial lnp(r;h)}{\partial h(l)}\right] \tag{22}$$

where $k,l=1,2,\mathrm{L},2N_{Bs}N_T L'$ because of the complex vector $\boldsymbol{h}$ with dimension of $N_{Bs}N_T L'\times 1$, $\partial lnp(r;h)/\partial h(k)$ denotes to take partial derivatives for the k-th component of $\boldsymbol{h}$. According to [12] we have

$$
\begin{aligned}
[I(h)]_{k,l} &= 2Re[\frac{\partial \mu^H(h)}{\partial h(k)} C^{-1}(h) \frac{\partial \mu(h)}{\partial h(l)}] \\
&= 2Re[\frac{p_k^H p_l + p_k^H d_l + d_k^H p_l + d_k^H d_l}{\sigma_w^2 I_N}] \\
&= \begin{cases} \frac{2E_p}{\sigma_w^2 / N}, & k = l \\ 0, & others \end{cases}
\end{aligned} \tag{23}
$$

here p_k and d_l indicate the *k*-th column vector of $\boldsymbol{p}$ and *l*-th column vector of $\boldsymbol{d}$ respectively. Then the CRB for an arbitrary channel estimator $\hat{h}_{j,i}$ with *L* order is given by:

$$CRB(\hat{h}_{j,i}) = L \times CRB(\hat{h})_{k,k} = \frac{L\sigma_w^2}{NE_p} \tag{24}$$

While the MSE of $\hat{h}_{j,i}$ has the relationship with $CRB(\hat{h}_{j,i})$ as follow:

$$MSE = E[\| h_{j,i} - \hat{h}_{j,i} \|^2] \geq CRB(\hat{h}_{j,i}) \tag{25}$$

C. Optimum Algorithm

In general, multipath channel is sparse in broadband wireless communication systems. The channel estimation accuracy can be improved by once knowing the PDP knowledge of channel. In [13], the GAIC criterion is applied to sparse channel estimation problem to estimate PDP in an iterative manner and obtain better performance. We extend this algorithm to the multi-cell cooperation scheme. Since the PDPs of different cells are not same and the PDPs of different transmit antennas in a cell are identical, for each cell only the PDP of channel estimator between the first transmit antenna and user, i.e., $\hat{h}_{1,i}$, $i = 1,2,L,N_{Bs}$, needs to estimate.

Then, for estimator $\hat{h}_{1,i}$, the GAIC cost function for a test channel order *l* has the form:

$$GAIC_{1,i}(l) = L'/2\, ln(\hat{\sigma}_{1,i;l}^2) + \gamma\, ln(ln(L'))(l+1) \tag{26}$$

γ is a user specified parameter, $\hat{\sigma}_{1,i;l}^2$ denotes the estimation of noise variance for channel order *l* and is given by

$$
\begin{aligned}
\hat{\sigma}_{1,i;l}^2 &= \frac{1}{L'}(\hat{h}_{1,i} - \hat{h}_{1,i;l})^H s_{1,i;L'}^H s_{1,i;L'}(\hat{h}_{1,i} - \hat{h}_{1,i;l}) \\
&= \frac{1}{L'}(\hat{h}_{1,i} - \hat{h}_{1,i;l})^H N I_{L'}(\hat{h}_{1,i} - \hat{h}_{1,i;l})
\end{aligned} \tag{27}
$$

where $\hat{h}_{1,i;l}$ is the channel estimator for channel order l and padded with $L'-l$ zeros. $s_{1,i;L'}$ is the submatrix from $\mathbf{s}_{1,i}$ retaining only the first L' columns with dimension of $N \times L'$.

The GAIC test is executed as algorithm 1:

Algorithm 1 GAIC Algorithm Processing

1: Initially set $P = L_{CP}$;

2: Calulate the cost function $GAIC_{1,i}(l)$ for $l = 1,\cdots,P$;

3: Obtain GAIC estimator as $\hat{L} = \arg\min_L \{GAIC_{1,i}(l)\}$;

4: Remove the effect of the newly estimated tap by setting $\hat{h}_{1,i}(\hat{L}) = 0$;

5: Set $P = \hat{L} - 1$ and repeat steps 2-4 to estimate the next significant tap positions;

6: If $\hat{L} \neq 1$ go to step 4.

Then the set $\{\hat{L}\}$ gives the positions of significant channel taps and it could be utilized to improve performance of the estimator as

$$\hat{h}'_{j,i}(l) = \begin{cases} \hat{h}_{j,i}(l), & l \in \{\hat{L}\} \\ 0, & l \notin \{\hat{L}\} \end{cases} \tag{28}$$

where $j = 1,2,L,N_T$, $i = 1,2,L,N_{Bs}$. In addition, this algorithm must be satisfied with $L' > L_{CP} > \max\{W_i\}$, $i = 1,2,L,N_{Bs}$.

IV. Numberical Simulation Results

Simulations were carried out to demonstrate MSE and bit error rate (BER) performance of the proposed algorithms. An OFDM system is simulated with following parameters: center frequency $f_c = 2.2$ GHz, bandwith $B = 1/T = 5$ MHz, number of overall subcarriers $N = 512$, length of CP $L_{CP} = 24$, mobile speed $v = 30$ km/h. Each OFDM frame consists of $N = 50$ OFDM symbols. Comb-type pilot pattern is employed in system with number of pilot subcarriers $N_p = 128$ and pilot interval $D_f = 4$.

Assuming that the cells' number $N_{Bs} = 2$ in simulation model, one BS per cell and each BS equipped with N_T transmit antennas, each user has receive antennas $N_R = 2$. The system exploits SFBC and QPSK modulation.

Multipath Rayleigh fading channels are considered as 3GPP-TR-25.996 SCM Case II channel model, with order $L = 6$. While the multipath tap locations in PDPs contain different and are uniformly distributed over [0 2510] ns.

For the convenience of comparison, let $\Delta = 32 \leq \lceil N_p/(N_T \cdot N_{Bs}) \rceil$, $E_p = 1$ and define Eb/N0 as $(N_T \cdot E_p)/\sigma_w^2$. Parameter γ is chosen as 1.4.

Fig. 3 shows the MSE performance of the proposed pilot-aided multi-cell JCE algorithm (denoted as MC-TcJCE) and its optimum algorithm with GAIC (denoted as GAIC-MC-TcJCE) compares with the corresponding CRB. From the figure, we observe that the MSE of multi-cell JCE with PDPs knowledge known accurately coincides with the curve of CRB and it means the estimator is unbiased. At the same time, because of using L_b length to replace the accurate PDPs knowledge, the MSE performance of MC-TcJCE losses about 6 dB compared with CRB. However, due to optimization of GAIC, the MSE curve of GAIC-MC-TcJCE is close to CRB with Eb/N0 increasing.

Fig. 4 and Fig. 5 illuminate the BER performance comparison for various multi-cell JCE algorithms with transmit antenna of one or two, respectively. In Fig. 4, with BS each equipped with one transmit antenna, the BER of multi-cell JCE with PDPs knowledge known has slight performance loss as compared to the case of perfect

channel knowledge. For the case of MC-TcJCE, the loss is about 1.6 dB. While for GAIC-MC-TcJCE the BER curve is close to the BER of multi-cell JCE with PDPs known gradually. In figure 5, with BS each equipped with two transmit antennas, the BER performance of both MC-TcJCE and GAIC-MC-TcJCE get rapid and significant improvement and the curves have been close to 10^{-4} at low Eb/N0 (less than 12dB) . But with Eb/N0 increasing, due to existence of Doppler frequency shift, the BER curves of both algorithms encounter error floors at about 20dB of Eb/N0.

Since the system exploits SFBC multi-cell cooperative joint transmission in this paper, it is worthwhile to investigate its robustness against Doppler shifts due to user mobility. Fig. 6 shows the BER performance comparison for various mobile speed of user with one transmit antenna when the proposed MC-TcJCE algorithm is applied on system. From the figure, the conclusion can be drawn that the system is not sensitive to user velocity and is robust to Doppler shift.

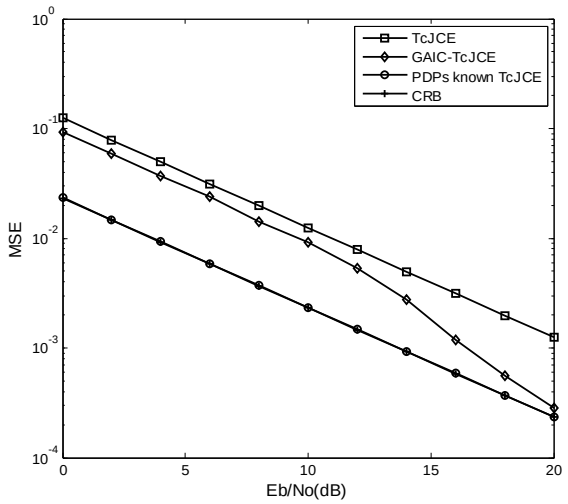

Figure 3. MSE performance comparison for various multi-cell JCE algorithms.

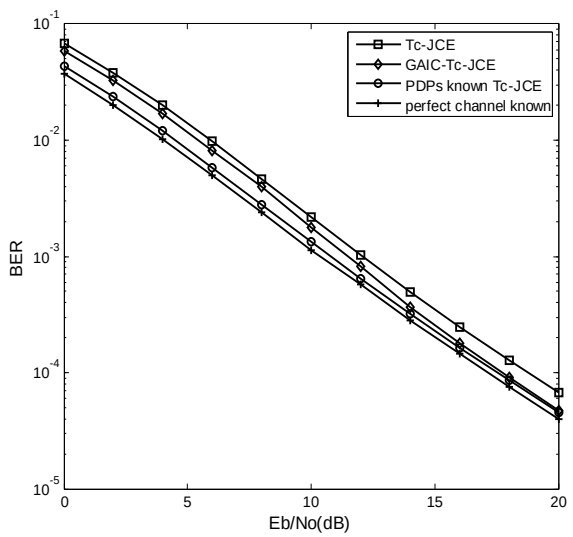

Figure 4. BER performance comparison for various MC-JCE algorithms with $N_T = 1$.

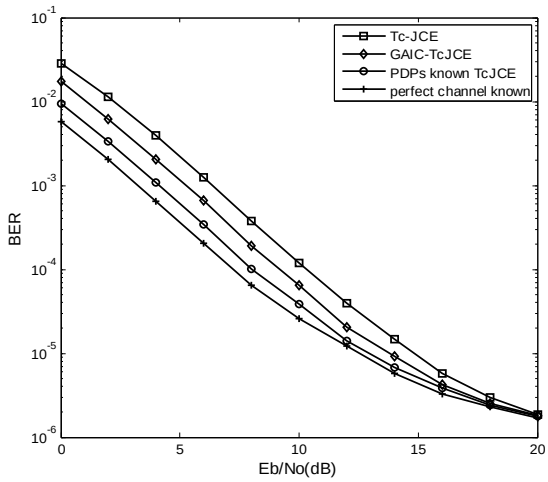

Figure 5. BER performance comparison for various JCE algorithms with $N_T = 2$.

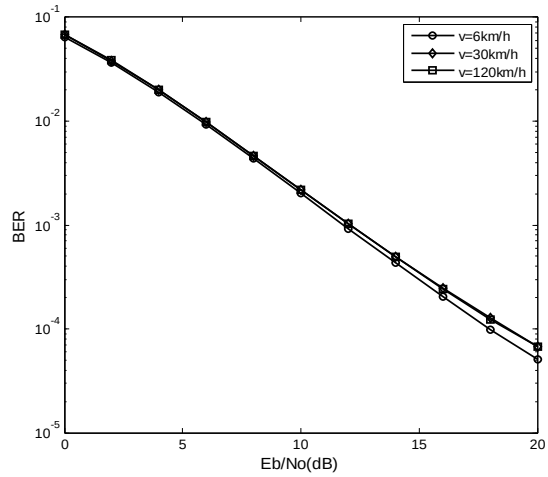

Figure 6. BER performance comparison for various mobile speed of user.

V. Conclusions

For multi-cell cooperation OFDM networks, this paper presents a time domain correlation based JCE algorithm when PDPs of multiple cells are not same and unknown by receiver. Then, by exploiting GAIC, the paper further optimizes the algorithm and obtains better performance. From simulation results we also note that compared with the corresponding CRB, the MSE performance of proposed algorithms has a certain loss. This performance gap provides a possibility to optimize the multi-cell JCE algorithms and it is a further need to study.

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