Modified Uniform Triangular Array for Online Full Azimuthal Coverage via JADE-MUSIC Algorithm over MIMO-CDMA Channel

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Abstract
This paper investigates a Modified Uniform Triangular Array (MUTA) to support online space-time MIMO-CDMA location based services with full azimuthal coverage via JADE-MUSIC algorithm. A new space-time lifting preprocessing (STLP) scheme is introduced as a decorrelating process of coherent signals through the dense/NLOS multipath MIMO channel before applying the JADE-MUSIC estimator. Uniform- H-Array (UHA) and Uniform-X-Array (UXA) geometries are established for performance comparisons with the proposed MUTA. Computer simulations under environment Matlab are described to illustrate the performance of online joint angle/delay estimation with MUTA-MIMO base station applying JADE-MUSIC in conjunction with STLP scheme in 360° azimuth region.

Keywords: *MIMO-CDMA, fading multipath proppagation, NLOS, array processing, coherent case, decorrelating scheme, JADE, MUSIC.*

1. Introduction

Multiple-Signal-Classification (MUSIC) [1-2], is introduced as the popular super-resolutive algorithm for location based services. Its well resistance to near-far situation and the high resolution capability, which theoretically is independent of the power of the multiple-access interference (MAI) [3], intersymbol interference (ISI) and noise effects, are important advantages over conventional estimation techniques. The high computational complexity streaming from the eigenvalue decomposition and limited capability in Non-Line-of-Sight (NLOS) high scattered multipath propagation conditions are on the other hand its major drawbacks. Such situation is usually encountered in multiuser (Multiple-Input Multiple-Output Code-Division Multiple-Access) MIMO-CDMA channel [4-5]. The received multipath signals are always highly correlated (coherent).The space-time covariance matrix (STCM) of incoming signals is therefore singular and nondiagonal. Furthermore, the high observation demand on antenna array required by the MUSIC algorithm make it unattractive for real-time tracking of space-time channel parameters. Rather, several preprocessing algorithms which aimed at decorrelating the coherent signals were proposed to support MUSIC algorithm. The “Bi-directivity smoothing scheme” introduced by Marius Pesavento in [6], “Spatial-Smoothing scheme” [7-8], and the “Modified Spatial-Smoothing scheme” [9] are most recent examples. Initially, these algorithms were proposed for direction-of-arrival estimation techniques in the case of uniform linear array (ULA) [10]. Thereafter, they have been associated to some estimation algorithms for jointly estimating AOA’s and delays of coherent signals [11-14]. Unfortunately, because the high spatial and temporal ambiguities arising from the coherent case over MIMO-CDMA communication channel, these algorithms do not achieve good estimation accuracy in space and time domains. Furthermore, they are restricted for only ULA geometry, which limit their capability in full azimuthal coverage [15].

In this paper, we present a new MUTA that achieves a full coverage in 360° azimuth region. Thereafter, the proposed MUTA will be used in conjunction with a new STLP decorrelating scheme to support online location based services via (joint angle and delay estimation with MUSIC) JADE-MUSIC algorithm. The proposed STLP scheme shows a good capability in resolving spatial and temporal ambiguity streaming from the coherent case through the MIMO-CDMA communication channel. Thus, it achieves a high decorrelation capability based on few data observation snapshots.

The rest of the paper is organized as follows. The MIMO-CDMA system model is presented in section 2. Section 3, presents the proposed JADE-MUSIC estimation method and gives details of STLP scheme and MUTA geometry. Computer simulations are described in section 4 to illustrate the performance of joint AOA/delay estimation with MUSIC algorithm in conjunction with STLP scheme and MUTA to support online full azimuthally coverage. Finally, some conclusions are drawn in section 5.

2. MIMO-CDMA System Model

Let us consider the uplink of an M-user asynchronous (16_QAM) MIMO-CDMA communication system operating in a multipath propagation environment. Assumed a Symbol-Rate-Maximization-Scheme (SRMS) is employed though the

MIMO channel. With this former scheme, each user is employing $\overline{N}$ transmit antennas whereas the base station has an array of N antennas. Assumed that the transmitted signal from the jth antenna element of the ith user arrives at the receiver via K_{ij} multipaths. Consider that the kth path due to the jth transmit antenna of the ith user is departing in direction having azimuth and elevation angles $(\overline{\theta}_{ij},\overline{\phi}_{ij})$ and arrives at the base station receiver from azimuth direction θ_{ijk} with channel propagation parameters β_{ijk} and τ_{ijk} representing the fading coefficient and path-delay, respectively [16]. The model in reception is simplified and only the one-dimensional case $(\theta,0)$ is taken into account.

The overall continuous-time baseband received signal-vector $X(t)$ due to the M users can hence be formulated as

$$X(t)=\sum_{i=1}^{M}\sum_{j=1}^{\overline{N}_i}\sum_{k=1}^{K_{ij}} S(\theta_{ijk})diag(\beta_{ijk})m_{ij}(t-\tau_{ijk})+N(t) \qquad (1)$$

For notational convenience, the received signal can be rewritten in a more compact form as

$$X(t)=\sum_{i=1}^{M}\mathrm{S}_i\cdot\mathrm{B}_i.\mathrm{M}_i(t)+N(t) \quad \in C^N \qquad (2)$$

where $\forall i\in\{1,2,...,M\}$

$$\begin{aligned}
&\mathrm{S}_i=[\mathrm{S}_{i1},\mathrm{S}_{i2},...,\mathrm{S}_{iN}]\in C^{N\times K_i}\\
&\mathrm{B}_i=\left[diag(\beta_{i1}^T),diag(\beta_{i2}^T),...,diag(\beta_{iN}^T)\right]^T\in C^{K_i}\\
&\mathrm{M}_i(t)=\left[M_{i1}^T(t),M_{i2}^T(t),...,M_{iN}^T(t)\right]^T\in C^{K_j}\\
&K_i=\sum_{j=1}^{\overline{N}}K_{ij}
\end{aligned} \qquad (3)$$

and $\forall j\in\{1,2,...,\overline{N}\}$

$$\begin{aligned}
&\mathrm{S}_{ij}=\left[S(\theta_{ij1}),S(\theta_{ij2}),...,S(\theta_{ijK_{ij}})\right]\in C^{N\times K_{ij}}\\
&\beta_{ij}=\left[\beta_{ij1},\beta_{ij2},...,\beta_{ijK_{ij}}\right]^T\in C^{K_{ij}}\\
&M_{ij}=\left[m_{ij}(t-\tau_{ij1}),m_{ij}(t-\tau_{ij2}),...,m_{ij}(t-\tau_{ijK_{ij}})\right]^T\in C^{K_{ij}}
\end{aligned} \qquad (4)$$

With

$$m_{ij}(t)=\sum_{n=-\infty}^{\infty}\overline{S}_i(\overline{\theta}_{ij},\overline{\phi}_{ij})\cdot I_{ij}[n]\ c_{PN,i}(t-nT_{cs}) \qquad (5)$$

where $\left\{I_{ij}[n]\in(\pm(2m-1)\pm(2m-1)j),\forall n\in \mathrm{Z}\quad with\quad m\in\left\{1,...,\frac{\sqrt{M}}{2}\right\}\right\}$ denote the ith user's sequence of M_QAM channel symbols transmitted by its jth antenna element during the nth channel symbol period T_{cs}, with

$$\overline{S}_i(\overline{\theta}_{ij},\overline{\phi}_{ij})=\sum_{j=1}^{\overline{N}_i}exp\left(-j\tfrac{2\pi}{\lambda_c}.\overline{\boldsymbol{u}}_i^{\boldsymbol{T}}(\overline{\theta}_{ij},\overline{\phi}_{ij})\overline{r}_{ij}\right)=\sum_{j=1}^{\overline{N}_i}exp\left(-j.\overline{k}_{ij}.\overline{r}_{ij}\right)$$

$$S(\theta_{ijk})=\sum_{j=1}^{N}exp\left(-j\tfrac{2\pi}{\lambda_c}.\boldsymbol{u}_{ijk}^{\boldsymbol{T}}(\theta_{ijk})r\right)=\sum_{j=1}^{N}exp\left(-j.k_{ijk}.r\right) \qquad (6)$$

represent the space array steering vector for the transmitting mobile terminal associated with the ith user and the space array steering vector associated with the kth path from the jth transmit antenna of the ith user at the receiving base station.

$\overline{\boldsymbol{r}}_{\boldsymbol{i}}=\left[\overline{r}_{i1},\overline{r}_{i2},...,\overline{r}_{i\overline{N}}\right]=\left[\overline{r}_{xi},\overline{r}_{yi},\overline{r}_{zi}\right]^T\in\Re^{3\times\overline{N}}$ and $\overline{k}_{ij}=(2\pi F_c/c).\left[cos\,\overline{\theta}_{ij}\cdot cos\,\overline{\phi}_{ij},\ sin\,\overline{\theta}_{ij}\cdot cos\,\overline{\phi}_{ij},\ sin\,\overline{\phi}_{ij}\right]^T$ are the transmit sensor location matrix and the wave number vector pointing towards the direction-of-departed (DOD) having azimuth and elevation angles $(\overline{\theta}_{ij},\overline{\phi}_{ij})$.

$r=[r_1,r_2,...,r_N]=[r_x,r_y,r_z]^T\in\Re^{3\times N}$ and $k_{ij}=(2\pi F_c/c).[cos\ \theta_{ijk},\ sin\ \theta_{ijk},\ 0]^T$ are the receiver sensor location matrix and the wave number vector pointing towards the AOA having azimuth direction θ_{ijk}.

$c_{PN,i}(t)$ denotes one period of the PN spreading waveform associated with the ith user and applied across all its transmitting antenna elements.

The noise vector $N(t)$ consists of N independent zero-mean complex Gaussian components with

$$E\{N(t)N^H(t)\}=\sigma_n^2\mathrm{I}_N \qquad (2)$$

where σ_n^2 is the power of the narrow-band noise.

The kth signal component of the received signal-vector $X(t)$ due to the jth receiving antenna element, $k\in\{1,2,...,N\}$ is therefore sampled at a constant sampling rate $F_s=1/T_c$ and then passed through a Tapped-Delay-Line (TDL) of length $2N_c$ time slots. In total, a bank of N-TDLs is available at the front-end of the receiving antenna array [17]. A Chip-Matched Filters may be employed at the input of each receiving antenna element. The 2Nc-dimensional discretised output frame due to the kth TDL at the n_o^{th} observation period is defined by $x_k[n_o]$ and the total formed discretised signal is represented by the complex matrix $\mathrm{X}[n]$,

$$\begin{aligned}
&\mathrm{X}[n]=\left[x_1^T[n],x_2^T[n],...,x_N^T[n]\right]\ \in C^{2NN_c\times L_{obs}}\\
&x_k[n_o]=\left[x_{k1}[n_o],x_{k2}[n_o],...,x_{k,2NN_c}[n_o]\right]^T\ \in C^{1\times L_{obs}}\\
&with\quad k\in\{1,2,...,N\},n_o\in\{1,2,...,L_{obs}\}
\end{aligned} \qquad (8)$$

L_{obs} denotes the observation length or the number of snapshots.

Using matrix notation, the discretised received signal can be expressed as a linear combination of the space-time array steering matrix H_i, the matrix of fading coefficients B_i, the message signal matrix M_i associated with the ith user and the noise matrix as following

$$\mathrm{X}[n] = \sum_{i=1}^{M} \mathrm{H}_i \cdot \mathrm{B}_i . \mathrm{M}_i[n] + \mathrm{N}[n] \quad \in C^{2NN_c \times L_{obs}} \tag{9}$$

With

$$\begin{aligned} &\mathrm{H}_i = [\mathrm{h}_{i1}, \mathrm{h}_{i2}, ..., \mathrm{h}_{iN}] \in C^{2NN_c \times K_i} \\ &\mathrm{h}_{ij} = \begin{bmatrix} S(\theta_{ij1}) \otimes \left(\mathrm{j}^{\,l_{ij1}} c_i\right), S(\theta_{ij2}) \otimes \left(\mathrm{j}^{\,l_{ij2}} c_i\right), ... \\ ..., S(\theta_{ijK_{ij}}) \otimes \left(\mathrm{j}^{\,l_{ijK_{ij}}} c_i\right) \end{bmatrix} \in C^{2NN_c \times K_{ij}} \\ &E\{\mathrm{N}[n].\mathrm{N}^H[n]\} = \sigma_n^2 \cdot \mathrm{I}_{2NN_c} \end{aligned} \tag{10}$$

l_{ijk} is the discrete version of the path-delay,

$$\tau_{ijk} = \frac{\sigma_{ijk}}{c}, \text{ i.e. } l_{ijk} = \left\lceil \frac{\tau_{ijk}}{T_c} \right\rceil mod\ N_c \tag{11}$$

c_i represents one period of the PN-sequence of the ith user padded with N_c zeros at the end. σ_{ijk} is the total kth path length due to the jth transmit antenna associated with the ith user and c is the propagation velocity. $S(\theta_{ijk})$ can be considered the space array steering vector or spatial signature and $\left(\mathrm{j}^{\,l_{ij2}} c_i\right)$ the time steering vector or temporal signature of the kth path due to the jth transmit antenna associated with the ith user. j is a $2N_c \times 2N_c$ shift operator matrix, having the following expressions:

$$\begin{cases} \mathrm{j} = \begin{bmatrix} 0 & 0 & . & . & . & 0 & 0 \\ 1 & 0 & . & . & . & 0 & 0 \\ 0 & 1 & . & . & . & 0 & 0 \\ . & . & . & & & . & . \\ . & . & & . & & . & . \\ . & . & & & . & . & . \\ 0 & 0 & . & . & . & 1 & 0 \end{bmatrix} = \begin{bmatrix} O^T_{2N_{C-1}} & 0 \\ I^T_{2N_{C-1}} & O_{2N_C-1} \end{bmatrix} \\ c_i = \left[\alpha_i(0), \alpha_i[1], ..., \alpha_i[N_c-1], O^T_{N_c}\right]^T \end{cases} \tag{12}$$

3. Proposed JADE-MUSIC Estimation Method

3.1 Proposed Space-time Lifting preprocessing (STLP) Scheme

Applying the maximum-likelihood estimation technique [18], we obtained the second order statistics of $\mathrm{X}[n]$ referred to as practical covariance for a finite observation interval equivalent to L_{obs} snapshots matrix as following

$$\hat{\mathrm{R}}_{XX} = \frac{1}{L_{obs}} \sum_{n=n_0-L_{obs}+1}^{n_0} \mathrm{X}[n]\mathrm{X}^H[n] \tag{13}$$

In order to apply the proposed iterative space-time lifting decorrelating scheme, a preprocessing scheme is carried out first. It merely ensures the passage from the temporal dimension of $\hat{\mathrm{R}}_{XX}$ to frequency domain. This transformation leads to an equivalent Vandermonde structure that will be exploited in the space-time lifting scheme. The preprocessed covariance matrix is defined as following,

$$\begin{aligned} \hat{\mathrm{R}}_P &= O_P . \hat{\mathrm{R}}_{XX} . O_P^H \\ &= \frac{1}{2} \tilde{\mathrm{H}} \cdot \mathrm{B} \cdot \mathrm{R}_{MM} \cdot \mathrm{B}^H \cdot \tilde{\mathrm{H}}^H + \sigma_n^2 \cdot \mathrm{I}_{2NN_c} \end{aligned} \tag{14}$$

with

$$\begin{aligned} &\tilde{\mathrm{H}} = \begin{pmatrix} \left[S(\theta_{1j1}), ..., S(\theta_{1jK_{1j}})\right], ... \\ ..., \left[S(\theta_{Mj1}), ..., S(\theta_{MjK_{Mj}})\right] \end{pmatrix} \otimes \begin{pmatrix} \left[\Psi^{l_{1j1}}, ..., \Psi^{l_{1jK_{1j}}}\right], ... \\ ..., \left[\Psi^{l_{Mj1}}, ..., \Psi^{l_{MjK_{Mj}}}\right] \end{pmatrix} \\ &and \quad \mathrm{R}_{MM} = E\{\mathrm{M}[n].\mathrm{M}^H[n]\} \in C^{K \times K} \quad , K = \sum_{i=1}^{M} K_i \end{aligned} \tag{15}$$

O_P is the pre-processing operator and such,

$$O_P = I_N \otimes \left(diag(1./(\mathrm{F} * c_d)) * \mathrm{F}\right) \tag{16}$$

F is the equivalent Vandermonde structure of the Fourier Transformation matrix,

$$\mathrm{F} = \begin{bmatrix} \phi^0 & \phi^0 & \phi^0 & . & . & . & \phi^0 \\ \phi^0 & \phi 1 & \phi^2 & . & . & . & \phi^{(2N_c-1)} \\ \phi^0 & \phi^2 & \phi^4 & . & . & . & \phi^{2(2N_c-1)} \\ . & . & . & . & & & . \\ . & . & . & & . & & . \\ . & . & . & & & . & . \\ \phi^0 & \phi^{(2N_c-1)} & \phi^{2(2N_c-1)} & . & . & . & \phi^{(2N_c-1)(2N_c-1)} \end{bmatrix} \tag{17}$$

$$with \qquad \phi = e^{-j\frac{\pi}{N_c}}$$

Once the preprocessed covariance matrix is obtained, the proposed STL scheme can be carried out.

Let us consider a ULA-MIMO base station with N receiving antennas and assumed a bank of N-TDLs with each of length $2N_c$ time slots is available at the front-end of the ULA.

The main goal of applying the proposed space-time lifting (STL) scheme is to track the space-time channel parameters of coherent signals within spatial and temporal domains related to the multiple antenna on the ULA and multiple time slots within the TDLs. The basic idea is to exploit the spatial and temporal redundancies arising from multiple antennas and multiple slots (by inter-sensors/slots or/and intra-sensors/slots tracking (ISST)) to isolate and to identify the varying space-time channel parameters through the preprocessed signal covariance matrix.

As similar to “Spatial-Smoothing scheme“, the N-ULA is divided into N_S overlapping subarrays, each of size L_S. Let sensors $\{1,2,...,L_S\}$ forming the first subarray, sensors $\{2,3,...,L_S+1\}$ forming the second subarray, and the sensors $\{N_S, N_S+1,...,N\}$ forming the $N_S{}^{th}$ subarray. The TDL associated with the jth receiving antenna element of the s^{th} subarray $\forall s \in \{1,2,...,N_S\}$ *and* $\forall j \in \{1,2,...,L_S\}$ is divided into N_T sub-TDLs each of size L_T time slots with the first sub-TDL stores the $\{1,2,...,L_T\}$ signal samples, the second sub-TDL stores the $\{2,3,...,L_T+1\}$ signal samples and $\{N_T, N_T+1,...,2N_c\}$ signal samples will be stored at the $N_T{}^{th}$ sub-TDL. L_S and L_T are considered the number of spatial and temporal shifts, respectively. As results, N_T temporal lifted preprocessed covariance sub-matrices are obtained within the $(L_S)^2$ submatrices associated with the s^{th} subarray formed by the $\{s, s+1,..., s+L_S\}$ receiving antenna elements, with $\{s=1,2,...N_S\}$. Finally, referring to the last details, the overall spatial-temporal lifted preprocessed covariance matrix is hence obtained as following

$$\begin{aligned}\hat{\mathrm{R}}_{STLP} = \frac{1}{N_S \cdot N_T}\sum_{s=1}^{N_S}\sum_{t=1}^{N_T} \tilde{\mathrm{H}}_{STL,s,t} \cdot \left(\vec{D}_{S,s}^{(s-1)} \otimes \vec{D}_{T,t}^{(t-1)}\right)\cdot \\ \mathrm{B}\cdot \mathrm{R}_{MM} \cdot \mathrm{B}^H \cdot \left(\vec{D}_{S,s}^{(s-1)} \otimes \vec{D}_{T,t}^{(t-1)}\right)^H \cdot \tilde{\mathrm{H}}_{STL,s,t}^H \\ + \hat{\sigma}_n^2 \cdot \mathrm{I}_{2L_S L_T}\end{aligned} \tag{18}$$

with

$$\vec{D}_{S,s} = diag\begin{pmatrix}\left[\sum_{s=1}^{L_S} S_{S,s}(\theta_{1j1}), \sum_{s=1}^{L_S} S_{S,s}(\theta_{1j2}),..., \sum_{s=1}^{L_S^{(i)}} S_{S,s}(\theta_{1jK_1})\right],... \\ ...,\left[\sum_{s=1}^{L} S_{S,s}(\theta_{Mj1}), \sum_{s=1}^{L_S} S_{S,s}(\theta_{Mj2}),..., \sum_{s=1}^{L_S} S_{S,s}(\theta_{MjK_M})\right]\end{pmatrix}$$

$$\vec{D}_{T,t} = diag\begin{pmatrix}\left[\sum_{t=1}^{L_T} \overset{l_{1j1}}{\Psi}_{T,t}, \sum_{t=1}^{L_T} \overset{l_{1j2}}{\Psi}_{T,t},..., \sum_{t=1}^{L_T} \overset{l_{1jK_1j}}{\Psi}_{T,t}\right],... \\ ...,\left[\sum_{t=1}^{L_T} \overset{l_{Mj1}}{\Psi}_{T,t}, \sum_{t=1}^{L_T} \overset{l_{Mj2}}{\Psi}_{T,t},..., \sum_{t=1}^{L_T} \overset{l_{MjK_{Mj}}}{\Psi}_{T,t}\right]\end{pmatrix} \tag{19}$$

where

$$\tilde{\mathrm{H}}_{STL,s,t} = \begin{pmatrix}\left[S_{S,s}(\theta_{1j1}),..., S_{S,s}(\theta_{1jK_{1j}})\right],... \\ ...,\left[S_{S,s}(\theta_{Mj1}),..., S_{S,s}(\theta_{MjK_{Mj}})\right]\end{pmatrix} \otimes \begin{pmatrix}\left[\overset{l_{1j1}}{\Psi}_{T,t},..., \overset{l_{1jK_{1j}}}{\Psi}_{T,t}\right],... \\ ...,\left[\overset{l_{Mj1}}{\Psi}_{T,t},..., \overset{l_{MjK_{Mj}}}{\Psi}_{T,t}\right]\end{pmatrix}$$

$$\begin{aligned}S_{S,s}(\theta_{ijk}) &= exp\left(-j\left[r_s, r_{s+1},..., r_{s+L_S}\right]^T k(\theta_{ijk})\right) \\ \overset{l_{ijK_{ij}}}{\Psi}_{T,t} &= \left[e^{-j\pi\frac{t.l_{ijK_{ij}}}{N_c}}, e^{-j\pi\frac{(t+1).l_{ijK_{ij}}}{N_c}},..., e^{-j\pi\frac{(t+L_T).l_{ijK_{ij}}}{N_c}}\right]\end{aligned} \tag{20}$$

3.2 Proposed JADE-MUSIC Algorithm

Referring to the Fig. 1, the proposed JADE-MUSIC algorithm is based on the eigenvalue decomposition of the spatial-temporal lifted preprocessed covariance matrix R_{STLP} provided by the space-time lifting preprocessing scheme. Eigenvectors of R_{STLP} are separated into two orthogonal subspaces, called the signal subspace $\mathrm{E}_{STLP}^{(Signal)}$ and noise subspace $\mathrm{E}_{STLP}^{(Noise)}$. If those eigenvectors which belongs to the noise subspace $\mathrm{E}_{STLP}^{(Noise)}$ are included in matrix $\hat{\mathrm{V}}_{noise}$, then the joint AOAs/Delays of incoming multipath signals can be estimated by locating peaks from the JADE-MUSIC spatial-temporal spectrum given by

$$\xi_{d,MUSIC}(\theta,l) = \frac{1}{w_{d,STLMF}^H(\theta,l).\hat{\mathrm{V}}_{noise}.\hat{\mathrm{V}}_{noise}^H.w_{d,STLMF}(\theta,l)} \tag{21}$$

With $w_{d,STLMF}(\theta,l)$ is the space-time lifted matched filter (STLMF) Beamformer associated to the desired user and used for scanning the spatial and temporal uncertainty regions. It is defined by the following expression,

$$\begin{aligned}w_{d,STLMF}(\theta,l) &= S_{SL}(\theta) \otimes \overset{l}{\Psi}_{TL} \\ S_{SL}(\theta) &= exp\left(-j\left[r_1, r_2,..., r_{L_S}\right]^T k(\theta, 0^\circ)\right) \\ \overset{l}{\Psi}_{TL} &= \left[1, e^{-j\pi\frac{l}{N_c}}, e^{-j\pi\frac{2l}{N_c}},..., e^{-j\pi\frac{(L_T-1)l}{N_c}}\right]\end{aligned} \tag{22}$$

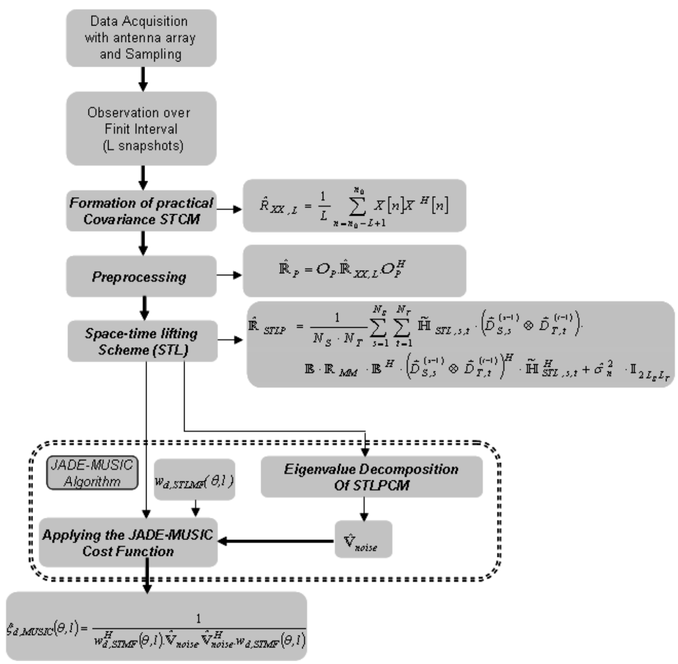


Fig. 1 Proposed JADE-MUSIC Algorithm.

3.3 JADE-MUSIC Algorithm with Proposed MUTA

The geometries of the proposed MUTA as well as those of UXA and UHA are depicted in Fig. 2.

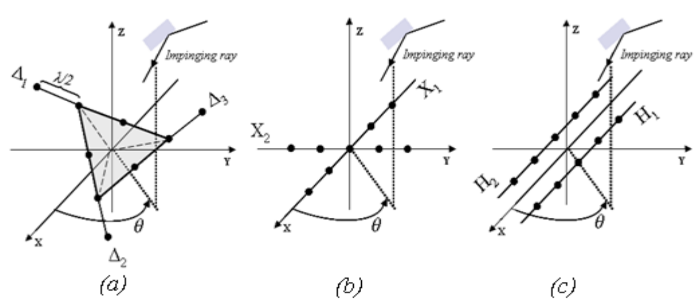


Fig. 2 (a): Proposed MUTA, (b): UXA, (c):UHA.

The JADE-MUSIC estimation algorithm using the proposed MUTA is carried out in several steps.

1.1.1 Step 1:

- Data acquisition and sampling for ULA of (Δ_1) to get $\mathrm{X}[n]^{(\Delta_1)}$.
- Data acquisition and sampling for ULA of (Δ_2) to get $\mathrm{X}[n]^{(\Delta_2)}$.
- Data acquisition and sampling for ULA of (Δ_3) to get $\mathrm{X}[n]^{(\Delta_3)}$.

1.1.2 Step 2:

- Formation of practical covariance matrix $\hat{\mathrm{R}}_{XX}^{(\Delta_1)}$.
- Formation of practical covariance matrix $\hat{\mathrm{R}}_{XX}^{(\Delta_2)}$.
- Formation of practical covariance matrix $\hat{\mathrm{R}}_{XX}^{(\Delta_3)}$.

1.1.3 Step 3:

- Space-time lifting preprocessing scheme for $\hat{\mathrm{R}}_{XX}^{(\Delta_1)}$ to provide $\hat{\mathrm{R}}_{STLP}^{(\Delta_1)}$.
- Space-time lifting preprocessing scheme for $\hat{\mathrm{R}}_{XX}^{(\Delta_2)}$ to provide $\hat{\mathrm{R}}_{STLP}^{(\Delta_2)}$.
- Space-time lifting preprocessing scheme for $\hat{\mathrm{R}}_{XX}^{(\Delta_3)}$ to provide $\hat{\mathrm{R}}_{STLP}^{(\Delta_3)}$.
- carry out the STLMF Beamformer $w_{d,STLMF}(\theta,l)$ to perform space-time scanning.

We proceeded with $N_S = 2$ overlapping subarrays, each of size $L_S = 3$ antenna elements for spatial lifting and $N_T = 7$ sub-TDLs each of size $L_T = 56$ time slots for temporal lifting.

1.1.4 Step 4:

- Compute eigenvalue decomposition of $\hat{\mathrm{R}}_{STLP}^{(\Delta_1)}$ to get the array eigenvalues $\hat{\Lambda}^{(\Delta_1)} = \left\{\hat{\lambda}_1^{(\Delta_1)} \geq \hat{\lambda}_2^{(\Delta_1)} \geq \hat{\lambda}_3^{(\Delta_1)} \geq \ldots \geq \hat{\lambda}_{k^{(\Delta_1)}}^{(\Delta_1)}\right\}$ and deduce $\hat{\mathrm{V}}_{noise}^{(\Delta_1)}$.
- Compute eigenvalue decomposition of $\hat{\mathrm{R}}_{STLP}^{(\Delta_2)}$ to get the array eigenvalue $\hat{\Lambda}^{(\Delta_2)} = \left\{\hat{\lambda}_1^{(\Delta_2)} \geq \hat{\lambda}_2^{(\Delta_2)} \geq \hat{\lambda}_3^{(\Delta_2)} \geq \ldots \geq \hat{\lambda}_{k^{(\Delta_2)}}^{(\Delta_2)}\right\}$ and deduce $\hat{\mathrm{V}}_{noise}^{(\Delta_2)}$.
- Compute eigenvalue decomposition of $\hat{\mathrm{R}}_{STLP}^{(\Delta_3)}$ to get the array eigenvalue $\hat{\Lambda}^{(\Delta_3)} = \left\{\hat{\lambda}_1^{(\Delta_3)} \geq \hat{\lambda}_2^{(\Delta_3)} \geq \hat{\lambda}_3^{(\Delta_3)} \geq \ldots \geq \hat{\lambda}_{k^{(\Delta_3)}}^{(\Delta_3)}\right\}$ and deduce $\hat{\mathrm{V}}_{noise}^{(\Delta_3)}$.

1.1.5 Step 5:

- Compute the JADE-MUSIC spatial-temporal spectrum $\xi_{d,MUSIC}^{(\Delta_1)}(\theta,l) = inv\left(w_{d,STLMF}^{H}(\theta,l).\hat{\mathrm{V}}_{noise}^{(\Delta_1)}.\hat{\mathrm{V}}_{noise}^{(\Delta_1)^H}.w_{d,STLMF}(\theta,l)\right)$ for space and time scanning regions $I_{S-scan}^{(\Delta_1)} = [0^\circ, 1^\circ, \ldots, 120^\circ]$, $I_{T-scan} = [0.\mathrm{T_c} : 1.\mathrm{T_c} : (\mathrm{N_c}-1).\mathrm{T_c}]$.
- Compute the JADE-MUSIC spatial-temporal spectrum $\xi_{d,MUSIC}^{(\Delta_2)}(\theta,l) = inv\left(w_{d,STLMF}^{H}(\theta,l).\hat{\mathrm{V}}_{noise}^{(\Delta_2)}.\hat{\mathrm{V}}_{noise}^{(\Delta_2)^H}.w_{d,STLMF}(\theta,l)\right)$

for space and time scanning regions $I_{S-scan}^{(\Delta_2)}=[121^\circ,122^\circ,...,240^\circ]$, $I_{T-scan}=[0.T_c:1.T_c:(N_c-1).T_c]$

- Compute the JADE-MUSIC spatial-temporal spectrum $\xi_{d,MUSIC}^{(\Delta_3)}(\theta,l)=inv\left(w_{d,STLMF}^{H}(\theta,l).\hat{V}_{noise}^{(\Delta_3)}.\hat{V}_{noise}^{(\Delta_3)^H}.w_{d,STLMF}(\theta,l)\right)$ for space and time scanning regions $I_{S-scan}^{(\Delta_3)}=[241^\circ,242^\circ,...,360^\circ]$, $I_{T-scan}=[0.T_c:1.T_c:(N_c-1).T_c]$
- Compute the total JADE-MUSIC spatial-temporal spectrum for the proposed MUTA,

$$\xi_{d,MUSIC}^{(MUTA)}(\theta,l)=\left[\xi_{d,MUSIC}^{(\Delta_1)}(\theta,l),\xi_{d,MUSIC}^{(\Delta_2)}(\theta,l),\xi_{d,MUSIC}^{(\Delta_3)}(\theta,l)\right]$$

- Plot $\xi_{d,MUSIC}^{(MUTA)}(\theta,l)$ for $x=[0^\circ,1^\circ,...,360^\circ]$, $y=[0.T_c:1.T_c:(N_c-1).T_c]$.

As similar to the JADE-MUSIC with MUTA, the total JADE-MUSIC spatial-temporal spectrum for the UXA is computed as following,

$$\xi_{d,MUSIC}^{(UXA)}(\theta,l)=\left[\xi_{d,MUSIC}^{(X_1,I_{S,X}^1)},\xi_{d,MUSIC}^{(X_2,I_{S,X}^2)},\xi_{d,MUSIC}^{(X_1,I_{S,X}^3)},\xi_{d,MUSIC}^{(X_2,I_{S,X}^4)}\right]$$ with $I_{S,X}^1=[0^\circ,...,90^\circ]$, $I_{S,X}^2=[91^\circ,...,180^\circ]$, $I_{S,X}^3=[181^\circ,...,270^\circ]$ and $I_{S,X}^4=[271^\circ,...,360^\circ]$.

Furthermore, the total JADE-MUSIC spatial-temporal spectrum for the UHA is computed as following,

$$\xi_{d,MUSIC}^{(UHA)}(\theta,l)=\left[\xi_{d,MUSIC}^{(H_1,I_{S,H}^1)},\xi_{d,MUSIC}^{(H_2,I_{S,H}^2)}\right]$$ with $I_{S,H}^1=[0^\circ,...,180^\circ]$ and $I_{S,H}^2=[181^\circ,...,360^\circ]$.

For both, UXA and UHA, the STLP scheme is carried out with $N_S=2$ overlapping subarrays, each of size $L_S=4$ antenna elements for spatial lifting and $N_T=5$ sub-TDLs each of size $L_T=58$ time slots for temporal lifting.

4. Simulation Results

Computer simulations under Matlab environment have been conducted to evaluate the joint AOA/delay estimation performance of the proposed JADE-MUSIC method using MUTA. The parameters used in the simulation are summarized in TABLE I.

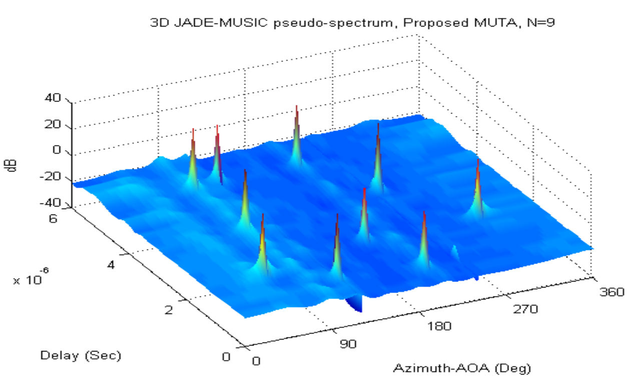
TABLE I. MIMO-CDMA SYSTEM SIMULATION PARAMETERS

System Parameters	**Notation**	**Parameter 's values**
Number of users	M	6
Number of data symbol/user	N_d	500
System Modulation	Mod	16_QAM
PN Gold-Sequences length	N_c	31
Chip period	T_C	200ns
Chip rate	$1/T_C$	$5Mchips/s$
Over sampling factor	q	1
Sampling period	$T_s=T_c/q$	200ns
Carrier frequency	F_C	2.4GHz
Number of Trans. Antenna	$\bar{N}_i$	2
Number of Receiv. Antenna	N	9 or 10

The space-time channel parameters for desired user are set to $[(203^\circ,3.T_c),(119^\circ,4.T_c),(60^\circ,7.T_c),(183^\circ,10.T_c),(121^\circ,25.T_c)]$ for 5 incoming multipaths associated with the first desired transmitted wave. For the second desired transmitted wave, are set to $[(90^\circ,15.T_c),(245^\circ,18.T_c),(300^\circ,10.T_c),(203^\circ,25.T_c),(90^\circ,24.T_c)]$.

Fig. 3 display the estimation of joint Azimuth-AOAs/delays of the 10 multipaths associated with the desired user applying the proposed JADE-MUSIC algorithm via MUTA. The proposed STLP scheme in conjunction with MUTA makes it possible to release completely the desired use from MAI, ISI and noise effects. Thus, the desired Azimuth-AOAs and delays are accurately estimated. All peaks were very narrow and the exactly coincide with the real Azimuth-AOA/delay, even in the case of co-delayed, co-directional, close-delayed and close-directional coherent signals. This revealed the high capability and super resolution of the proposed JADE-MUSIC estimation method. Which make it suitable for online tracking of space-time channel parameters of perfectly coherent multipath signals over MIMO-CDMA channel.

We not that all the simulation results are carried out with only $L_{obs}=10$ snapshots when forming the practical covariance matrix.



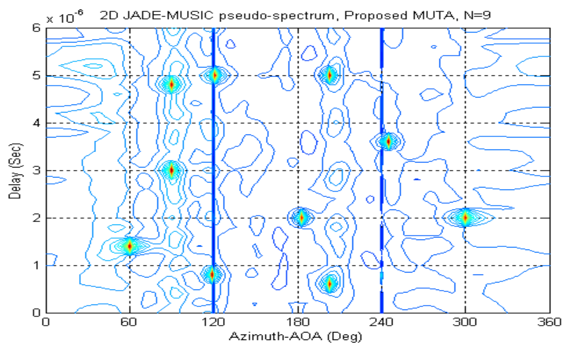


Fig. 3 Spatial-temporal 3D (upper plot) and 2D (lower plot) output pseudo spectrums of JADE-MUSIC algorithm with proposed MUTA.

Fig. 4 displays the output of JADE-MUSIC algorithm applying UXA. The 10 desired multipaths are well resolved; however we remark the appearance of two secondary peaks, which are marked by black crosses on 2D pseudo-spectrum. The desired signal subspace is estimated too smaller than the real one. Then the projection of any space-time steering vector into the noise subspace results in ISI and MAI, which explain the appearance of these additive peaks.

The estimation results with JADE-MUSIC algorithm via UHA are illustrated in Fig. 5. Only five peaks are clearly seen. The space-time channel parameters of some coherent signals where not resolved. Although we conserved the same interference environment considered in previous simulations depicted in Fig 3 and Fig. 4, the peaks provided with JADE-MUSIC via UHA are relatively broad and lower compared to those of JADE-MUSIC with UXA and proposed MUTA.

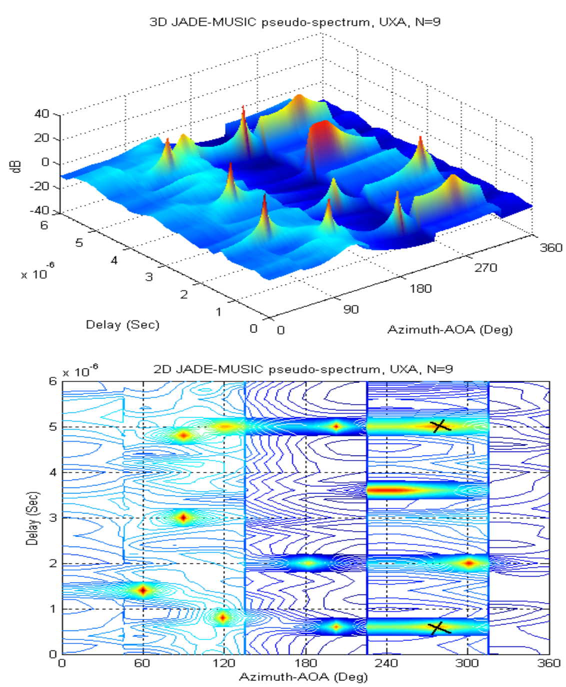


Fig. 4 Spatial-temporal 3D (upper plot) and 2D (lower plot) output pseudo spectrums of JADE-MUSIC algorithm with UXA.

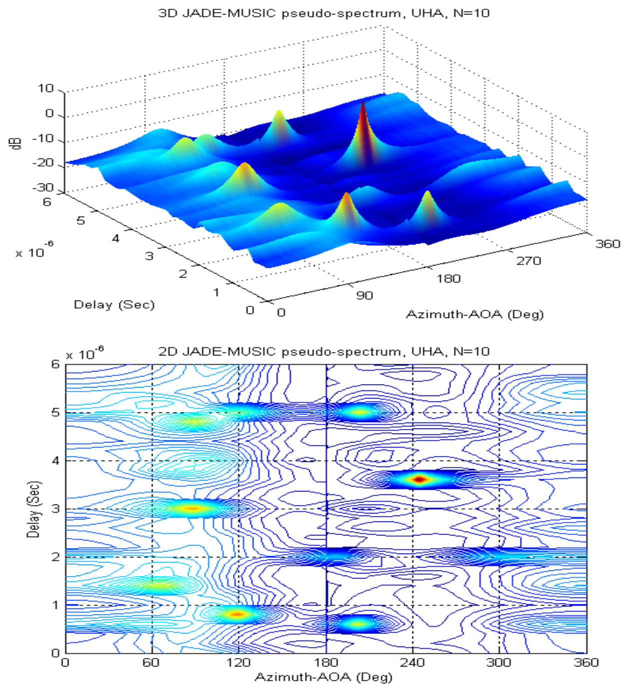
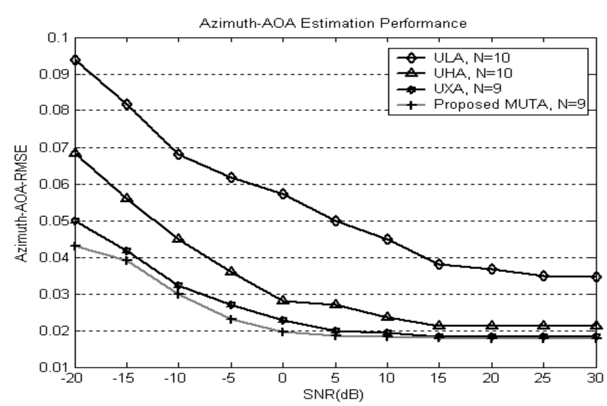


Fig. 5 Spatial-temporal 3D (upper plot) and 2D (lower plot) output pseudo spectrums of JADE-MUSIC algorithm with proposed UHA.

Fig. 6 displays the azimuth-AOA/Delay root mean square error (RMSE) performance versus the Signal-to-Noise-Ratio (SNR) for the proposed JADE-MUSIC estimation method with different array geometries. It is clearly seen that the JADE-MUSIC algorithm with the proposed MUTA is with high spatial and temporal resolutions compared to the JADE-MUSIC via UHA and ULA, respectively. The performance of UXA is comparable to that of MUTA in all SNR conditions and they are very close especially for delays parameters. Although, the number of antenna elements in UHA and ULA is greater than that of MUTA and UXA, they do not provide the space-time channel parameters of all desired incoming multipaths. This revealed that the UHA and ULA are not suitable for full azimuthally tracking.



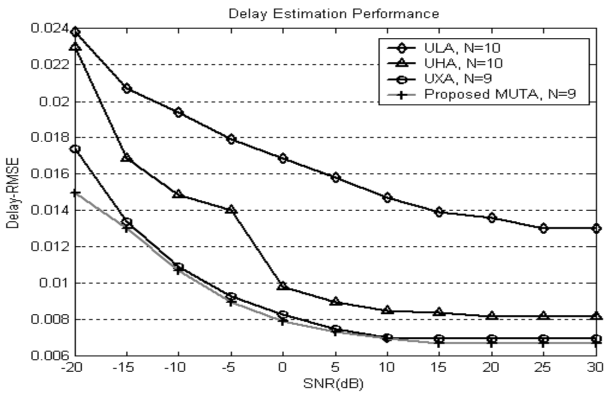


Fig. 6 Azimuth-AOA (upper plot) and delay (lower plot) RMSE estimation performance versus SNR for different array geometries.

5. Conclusions

A modified uniform triangular array (MUTA) in conjunction with a new STLP decorrelating scheme are proposed in this paper to support JADE-MUSIC online full azimuthal tracking of coherent signals over MIMO-CDMA channel. With this STLP former scheme and MUTA geometry, the proposed JADE-MUSIC estimation method can achieve a high spatial and temporal decorrelating capability and ensure a full coverage in 360° azimuth region. Computer simulations show that the JADE-MUSIC algorithm with proposed MUTA outperforms that of UXA, UHA and ULA geometries.

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