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gold-MUSIC based DOA estimation using ULA antenna of DS-CDMA sources with propagation delay diversity

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ABSTRACT

Direction of Arrival (DOA) estimation using *gold*-MUSIC is achieved for Uniform Linear Array (ULA) antenna based Direct-Sequence Code Division Multiple Access (DS-CDMA) sources having different Propagation Delay. The DOA is estimated by different MUSIC (Multiple Signal Classification) algorithms for M signal sources with Phase Shift Keying (PSK) transmission in presence of Additive White Gaussian Noise (AWGN). Spatial spectrum, computational efficiency and Root Mean Square Error (RMSE) of DOA estimation using *gold*-MUSIC over MUSIC and Root-MUSIC algorithms are studied meticulously. The effects of number of ULA elements, Data length and arrival angle on RMSE of DOA are also conferred here.

1. Introduction

Direct-Sequence Code Division Multiple Access (DS-CDMA) technology is deployed in the air interface as the backbone of third generation (3G) wireless systems [1–3]. The demand for improved adaptive antenna array DS-CDMA system performance is increasing because of its advantageous implementation and security related applications. Multiple Access (MA) allows efficient use of wireless bandwidth. Spread-spectrum communication achieves excellent potential of large bandwidth and very low forward error control coding [4].

Coherence detection requires exact channel estimation [5]. Antenna arrays at base station of Multicarrier (MC) DS-CDMA system enable estimation of space-time and channel parameters with user locations [6–8]. Receiver antenna arrays detect the information by suppressing interference, exploiting Pseudo Noise (PN) code, users spatial separation and space-time processing [9,10].

In practice, proper Direction of Arrival (DOA) estimation by Multiple Signal Classification (MUSIC), Estimation of Signal Parameters via Rotational Invariance Techniques (ESPRIT), etc. algorithms require more number of array elements than the number of active users [9,11]. DOA estimator with code-matched filters and parallel MUSIC models the interference from other users as Gaussian noise [12]. As the spatial spectrum interval goes coarser, MUSIC gives less accurate results [13]. Root-MUSIC can be applied only to Uniform Linear Array (ULA) antenna for improving accuracy with no dependency on spatial spectrum interval [13]. *gold*-MUSIC employed with any antenna array geometry provides more accurate results, less complexity and computational advantage than MUSIC and Root-MUSIC [13].

gold-Section Univariate (GSU) method provides excellent results with lower number of iterations, smaller number of snapshots and lower Signal to Noise Ratio (SNR) [13]. *gold*-MUSIC offers improved Root Mean Square Error (RMSE), resolution, complexity, SNR sensitivity and calibration sensitivity of estimated DOA as compared to Delay and Sum (DAS), Max entropy, Capon, MUSIC, Root MUSIC and ESPRIT techniques [14,15]. Generalised (G)-MUSIC, Matching Pursuit (MP)-MUSIC, $\ell_{1,2}$-MUSIC and M$\ell_{1,2}$-MUSIC are joint approaches of Compressive Sensing (CS) and MUSIC for DOA estimation in presence of multipath [16]. *gold*-MUSIC can further enhance estimation performance of combined CS and MUSIC approaches.

Sparse aperodic arrays accomplish any design by utilizing least possible active array elements with enough degrees of freedom in that task [17]. *gold*-MUSIC can be applied for DOA estimation by sparse aperiodic antenna arrays following similar procedure of working with ULA. Mapping of source covariance matrix for sparse aperiodic arrays to ULA of same aperture facilitates desired outcome [18]. *gold*-MUSIC DOA estimate using sparse aperiodic arrays designed by CS approach can offer subsequent deterministic and probabilistic advantages [17].

This paper assesses ULA based DOA estimation of DS-CDMA sources employing *gold*-MUSIC. The Propagation Delay diversity in presence of Additive White Gaussian Noise (AWGN) and Near-Far effect are also incorporated in the system model. The DOA is estimated for signal sources with Phase Shift Keying (PSK) transmission in non-overlapping time frame. The GSU method used here is applied to the objective function itself for obtaining the ceiling. It is easy to implement, facilitated by Golden Ratio with very small number of iterations. In this article, fast realization of DOA values is achieved with single scan and

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very low complexity. Spatial spectrum, RMSE and computational complexity of DOA estimate by *gold*-MUSIC compared to Root MUSIC and MUSIC are detailed here. The impact of different Data length, number of ULA elements and arrival angle on RMSE of DOA are also studied for different MUSIC algorithms.

2. ULA antenna based DS-CDMA

The data security associated with spread spectrum technology escalates the interest in Direct Sequence Spread Spectrum (DSSS) communication. The Near-Far effect is experienced by the DS-CDMA receiver due to variations in power received. Due to efficient bandwidth and power utilization property, the DSSS system is suitable for operating in Near-Far environment. In DS-CDMA, multiple users share the whole channel bandwidth and are multiplexed by PN codes [3,5,19,20].

The DS-CDMA signal for m^{th} user passing through the transmission medium is [7,21,22],

$$s_{DS_m}(t) = g_m\sqrt{P_m}\,d_{k_s}^{(m)}c_{G_m}(t) \tag{1}$$

The sampling instant is $t = k_sT_s$, where the sampling interval is T_s and k_s is an integer. The chip duration is $T_c = T_s/L_c$, where L_c is Spreading Factor. The PSK transmitted data in single T_s for m^{th} user is $d_{k_s}^{(m)}$. The m^{th} user signal strength is $g_m\sqrt{P_m}$. The m^{th} user scalar gain for channel is g_m. The transmission power for m^{th} user is P_m. $c_{G_m}(t)$ is the Gold code sequence operating as the PN code for m^{th} user. The DS-CDMA signal in Near-Far effect for m^{th} user can be deduced from Eq. (1) as,

$$s_{DSnf_m}(t) = g_m\sqrt{P_{nf_m}}\,d_{k_s}^{(m)}c_{G_m}(t) \tag{2}$$

where the Near-Far power received for m^{th} user is P_{nf_m}.

The channel spatial aspect, i.e., incoming signal DOA is exploited by utilizing beamforming techniques for tracking and separating signals [23–25]. Array antennas improve the performance of DS-CDMA systems by reducing Multiple Access Interference (MAI) [26–29]. Suppose, E_b is Energy per bit and $N_0/2$ is AWGN Power Spectral Density (PSD). Then, SNR is $2E_b/N_0$ and noise variance for single antenna receiver is [28],

$$\sigma_N^2 = \frac{N_0}{2} \tag{3}$$

Let, N is the number of omnidirectional antenna elements. In receiver consisting of antenna array, the noise power is reduced by N times as compared to that of single antenna receiver. So, the noise variance of receiver consisting of antenna array becomes [28],

$$\overline{\sigma}_N^2 = \frac{\sigma_N^2}{N} = \frac{\frac{N_0}{2}}{N} \tag{4}$$

In general, when the DS-CDMA signals impinge on the ULA system of N elements from M signal sources in Near-Far environment, the received signal by n^{th} array element is [30–33],

$$x_n(t) = \sum_{m=1}^{M} s_{DSnf_m}(t)e^{-j2\pi\frac{d_n}{\lambda}\sin\theta_m} + n_n(t) \tag{5}$$

where d_n is the distance between n^{th} and reference antenna array element. θ_m is the DOA of the m^{th} signal source. λ is the carrier signal wavelength of signal sources and $n_n(t)$ is the additive noise.

Let the ULA elements have half wavelength inter-element spacing. Then the received signal by the ULA can be enumerated as [14,32],

$$\mathbf{x}(t) = \mathbf{A}\mathbf{s}(t) + \mathbf{n}(t) \tag{6a}$$

$\mathbf{x}(t)$ is $N \times 1$ vector given as,

$$\mathbf{x}(t) = [x_1(t)x_2(t)x_3(t)\ldots x_N(t)]^T \tag{6b}$$

$\mathbf{s}(t)$ is $M \times 1$ vector given as,

$$\mathbf{s}(t) = \left[s_{DSnf_1}(t)s_{DSnf_2}(t)s_{DSnf_3}(t)\ldots s_{DSnf_M}(t)\right]^T \tag{6c}$$

$\mathbf{n}(t)$ is $N \times 1$ vector given as,

$$\mathbf{n}(t) = [n_1(t)n_2(t)n_3(t)\ldots n_N(t)]^T \tag{6d}$$

The array factor $\mathbf{A}$ is an $N \times M$ matrix, whose m^{th} column is given as,

$$\mathbf{a}(\theta_m) = \left[1e^{-j\pi\sin\theta_m}e^{-j2\pi\sin\theta_m}\ldots e^{-j(N-1)\pi\sin\theta_m}\right]^T \tag{6e}$$

When the signals impinging on ULA have same delay, then, at any instant, the received signal by n^{th} array element follows Eq. (5). When signals impinging on ULA have different delay, so that, they can occur in non-overlapping time frame, then, at any instant, the n^{th} array element gets the signal from single signal source. Thus, received signal has no MAI effect and is given as,

$$x_{0n}(t) = s_{DSnf_0}(t)e^{-j2\pi\frac{d_n}{\lambda}\sin\theta_0} + n_{0n}(t) \tag{7}$$

where $s_{DSnf_0}(t)$ is the DS-CDMA signal transmitted by the signal source with DOA of θ_0 and $n_{0n}(t)$ is the additive noise.

3. DOA estimation using *gold*-MUSIC

The DOA estimated by MUSIC algorithm gives sharp peak at arriving angle with minimized magnitude at other angles [13]. The received signal by ULA in Eq. (7) is taken as the input of this estimator. The DS-CDMA Data length is given as,

$$L_t = L_dL_c \tag{8}$$

where L_d is the actual Data length.

The input covariance matrix is calculated as,

$$\mathbf{R}_{xx} = \frac{1}{L_t}\sum_{l=1}^{L_t} x_{0n}(t_l)x_{0n}^H(t_l) \tag{9}$$

Eigenvalue decomposition on the covariance matrix gives the eigenvectors $\mathbf{E_N}$. The DOA of DS-CDMA user by MUSIC is provided by the objective function as [15],

$$P(\theta) = \frac{1}{\mathbf{a}^H(\theta)\mathbf{E_N}\mathbf{E_N}^H\mathbf{a}(\theta)} \tag{10}$$

where θ is the scanning angle.

The polynomial of $\mathbf{E_N}$ is solved in Root-MUSIC DOA estimation. GSU minimization applied on the coarse of $P(\theta)$ avails the arrival angles in *gold*-MUSIC [13].

GSU locates the extreme of a univariate function by consecutively reducing the range within which extreme is supposed to occur. Let the coarse interval is θ_a to θ_b with $\theta_a < \theta_b$ in the DOA interval of $-90°$ to $90°$. The intermediate points θ_c and θ_d are chosen as [34],

$$\theta_c = \theta_a + g(\theta_b - \theta_a) \tag{11a}$$

$$\theta_d = \theta_b - g(\theta_b - \theta_a) \tag{11b}$$

where the Golden Ratio is given as,

$$g = (\sqrt{5} - 1)/2 \tag{11c}$$

$P(\theta)$ is evaluated at θ_a, θ_b, θ_c and θ_d. If $P(\theta_d) > P(\theta_c)$, then $\theta_b = \theta_c$ and $\theta_c = \theta_d$, else $\theta_a = \theta_d$ and $\theta_d = \theta_c$ in the next iteration. Moderate number of iterations can provide DOA value accurately.

The RMSE of DOA estimate is calculated by [15],

$$\text{RMSE} = \sqrt{\frac{1}{R_t}\sum\nolimits_{e=1}^{R_t}(\theta_e - \theta_0)^2} \tag{12}$$

where θ_e is the estimated DOA for e^{th} snapshot, θ_0 is the real DOA and R_t is number of runtimes.

The time complexity of DOA estimation algorithms are given as [13,35,36]. C_M is the coarse scanning angle for MUSIC. Table 1 explains