Analysis and estimation of direction of arrival for smart antennas by using a novel filtering algorithm

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Abstract

For solving the main conflict between the direction of arrival for the radio signal and maintaining the signal details in the wireless communication, this paper presents a novel algorithm for improving the radio signal processing. In order to receive the strongest radio wave from the antenna array, the direction estimation for wireless communication is approached under radio electromagnetic spectrum broadband, in which there are the multiple transmitting antennas and the multiple receiving antennas. We construct the focusing matrix for each frequency point, and then we use the uniform linear array to establish a mathematical model to simulate the direction of arrival for the smart antennas.

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Keywords: Signal interference; direction of arrival; smart antenna; novel filtering algorithm.

1. Introduction

Currently, under very kinds of electromagnetic interferences, one of great challenges faced by the wireless communication is how to meet the rapidly growing demand for wireless services and how to fully apply the limited radio spectrum. For eliminating the electromagnetic interference, the cognitive radio technology (CRT) has been proposed as a promising solution way for the challenge [1]. In a radio electromagnetic spectrum based on the cognitive radio network, the secondary users (SU) are allowed to coexist with the primary user (PU), because there exists some constraint condition, namely the

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interference constraint condition, so that the interference power from the SU to the PU is less than an acceptable value. We consider the direction of arrival (DOA) of the secondary users (SU), in which the secondary users can use a multiple-input single-output (MISO) channel, and the primary user (PU) has only one receiving antenna. We also consider the direction of arrival (DOA) of the SU under the situation of the channel state information (CSI) about the SU link is not very perfect at the secondary user transmitter (SU-Tx), and there is not good cooperation between the SU and the PU. The study of broadband signal has gotten some considerable attention for the DOA estimation in the past [2]. They also pointed out that if the focusing matrix and its transposed matrix are independent with frequency, and constructed a diagonal matrix to simplifying the calculation process, but there is some loss of focus [3], and if there is some inappropriate initial value of the direction, the ability of convergence for the algorithm will be reduced, and cause the estimation biasing [4]. In order to eliminate the electromagnetic interferences, a novel algorithm for the estimation of the direction of arrival (DOA) is presented under radio electromagnetic spectrum broadband. In the paper, we proposes the feedback-based adaptive frequency algorithm, and constructs the focusing matrix for each frequency point, then uses the uniform linear array to establish a mathematical model for estimating the direction of arrival (DOA).

2. Direction model for wideband radio signal

In Fig.1, the main user network is constructed by the primary user transmitter (PU-Tx) and the primary user receiver (PU-Rx). The network of the user is constructed mainly by the secondary user transmitter (SU-Tx) and the secondary user receiver (SU-Rx), which have some antennas, and the number of the antennas is N. When the two networks share the same frequency band, the user receiver (SU-Rx) receives the signals coming from the secondary user transmitter (SU-Tx) and the interference signal coming from the primary user transmitter (PU-Tx). We can consider a point-to-point communication system for a multiple-input single-output (MISO) of the secondary user, in which the secondary user has N transmit antennas and a single receiving antenna. The radio signal receiving model of the secondary user can be represented, as \( y = h_s x + n \), where \( y \) receives the signals, and \( x \) transmits the signals respectively; \( h_s \) denotes the \( N \times 1 \) channel response from the (SU-Tx) to the (SU-Rx), and \( n \) is independent receiving point. The power of (SU-Tx) is \( P_s \), and it will be assigned among the various antennas, and the power of (PU-Tx) is \( P_p \); \( \sigma_p^2 \) is the complex Gaussian variable for (PU-Tx). Supposing the transmitter power and the channel state condition are all workable. The signal to noise ratio \( r_o \) should be achieved maximum, when \( h_s \) and \( h_s \) is orthogonal. Based on the system model shown on Fig.1, the noise ratio \( r_o \) for the main receiver is shown,
\[
r_0 = \frac{P_p |h_s|^2}{P_s / \sum |h_s h_p|^2 + \sigma_p^2}
\] (1)

3. Estimating algorithm for direction of arrival

Supposing the number of broadband sources for \((SU-Tx)\) is \(N\), and the bandwidth is \(B\). They can arrive to the \((SU-Rx)\) from different direction, then the received signal can be expressed as following,

\[
h_s(t) = \sum_{n=1}^{N} s_n(t - \tau_n) + N(t)
\] (2)

in which, \(S_n(t)\) is the signal source of \(N\)th; \(\tau_n\) is the delay time for signal source arrival at \((SU-Rx)\), \(N(t)\) is additive noise of \((SU-Rx)\) and a part of \(h_p(t)\). Because there exists the relation between the direction of the broadband signal and the frequency of the signal, it can’t be represented as an expression vector matrix in the time domain. So, it can only be described by the frequency mode. If the observation period \(T_0\) is divided into the sub-segments \(T_d\), which number is \(K\). To observe the data points, the Discrete Fourier Transform should be done, and then the following array output broadband signal model is obtained,

\[
h_s(f_j) = A(f_j)s_n(f_j) + N(f_j)
\] (3)

In the formula, \(J\) is a decomposed point of the bandwidth of \(B\) and non-overlapping sub-bands. \(H_s(f_j)\) is the received signal vector for \((SU-Rx)\) under the frequency \(f_j\), \(S(f_j)\) are the spectral components for the source signal under the frequency \(f_j\), \(N(f_j)\) are the spectral components for the noise under the frequency \(f_j\), \(A(f_j)\) is the flow pattern under the frequency \(f_j\). Therefore, the vectors for the flow pattern and direction is follows,

\[
A(f_j) = [a(f_j, \theta_1) a(f_j, \theta_2) \cdots a(f_j, \theta_n)]
\] (4)

\[
a_n(f_j) = e^{-j2\pi f_j \tau_n}
\] (5)

The coherent signal subspace method is used to focus the various frequencies within the bandwidth under the reference frequency signal subspace. A focusing matrix \(T(f_j)\) is constructed by \(A(f_0) = T(f_j)A(f_j)\) to do the DOA estimation. Focusing matrix \(T(f_j)\) should meet the following conditions,

\[
\min \| A(f_0) - T(f_j)A(f_j) \|^2 , j = 1, \ldots, J
\] (6)

\[
T(f_j)T^H(f_j) = I
\] (7)
We can solve the equation (6) and (7), and we have

\[ T(f_j) = V_0 V_j^H \]  \hspace{1cm} (8)

where \( V_0 \) and \( V_j \) are the left and right singular vector matrix for \( A(f_0)A(f_j)^H \). After getting the transformation matrix \( T(f_j) \), the frequency conversion is done for the data points in each channel of \( SU-Tx \).

\[ Y_{nj}(f_j) = T(f_j)Y_j(f_j) \quad n=1,2\ldots N \]  \hspace{1cm} (9)

Then, we can do the average processing for the changing channel:

\[ Y_j(f_0) = \frac{1}{N} \sum_{n=1}^{N} Y_{nj}(f_0) \quad j=1,2\ldots N \]  \hspace{1cm} (10)

After getting the focus on the reference frequency \( f_0 \), the DOA estimation can be done as the narrow-band. The output covariance matrix is following,

\[ \hat{R} = \frac{1}{J} \sum_{j=1}^{J} Y_j(f_0)Y_j^H(f_0) \]  \hspace{1cm} (11)

The covariance matrix \( \hat{R} \) is got by the eigenvector decomposition, and the corresponding eigenvectors is formed the noise subspace estimate. The signal subspace after the focus and the noise subspace \( E_N \) are orthogonal.

\[ a^H(f_0)E_N = 0 \]  \hspace{1cm} (12)

At last, the peak searching for the one-dimensional spectral is done to get a peak location which is the value of the DOA estimation,

\[ P(\theta) = \frac{1}{a^H(f_0)E_N^\omega a(f_0)E_N^H} \]  \hspace{1cm} (13)

4. Simulation results for the novel algorithm

In this paper, the simulation is given to prove the effective of the algorithm, and we give also the relation among the direction estimation precision, signal noise ratio and the bandwidth. The antenna array is the eight directional array elements, and it composes of uniform linear array. The array spacing is the half wavelength with the signal centre frequency; but the noise is the zero-mean Gaussian white noise.

We calculate the impact of the root mean square error for direction estimated with the SNR. For the two coherent broadband signals, in which SNR is changed in the 1 ~ 40 dB, the impact of the root mean square error for direction estimated with the SNR can be shown in Fig.2 (a). The root mean square error for
direction estimated is reduced, when the SNR increases. We can also calculate the impact of the root mean square error for direction estimated with the relative bandwidth. The relative bandwidth of the two coherent broadband signals is between 0.1 and 0.5. The impact of the root mean square error for direction estimated with the relative bandwidth can be shown in Fig.2 (b). With the relative bandwidth increasing, the direction of the estimated root mean square error is changed a little. When the relative bandwidth is 35%, the root mean square error is minimal.

Fig.2. (a) The root mean square error for DOA with SNR; (b) The root mean square error for DOA with the bandwidth.

5. Conclusions

For eliminating the electromagnetic interferences, we establish a mathematical model for estimating the direction of arrival (DOA), and we can do the conjugate reconstruction well. The simulation results show that the algorithm has a good resolution, and it has less computational complexity and becomes easier to implementation in engineering.

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