Adaptive Interference Suppression in Communication Systems using Direct Data Domain Least Squares (D3LS) Approach

#Santana Burintramart, Akkarat Boonpoonga†, and Tapan K. Sarkar

Department of Electrical Engineering and Computer Science
Syracuse University, Syracuse, NY 13244, USA
sburintr@syr.edu and tksarkar@syr.edu

†Department of Computer Engineering, Mahanakorn University of Technology
Nongchok, Bangkok 10530, Thailand.
akkarat@mut.ac.th

1. Introduction

Adaptive array has been introduced to wireless communications to enhance frequency reuse by adaptively suppress undesired signals and receive only the desired one. Many methods have been proposed in the literature including least mean squares (LMS) [1], recursive least squares (RLS) [2], sample matrix inversion (SMI) [3], and their other variation forms [4]. The major deficiencies of these methods are their convergence rate and the required training sequence. Even though another type of adaptive algorithms, such as constant modulus algorithm (CMA) [5], has been introduced to solve the training issue, it is also sensitive to its initial condition [6].

In contrasts to the classical methods, the direct data domain least squares (D3LS) algorithm has been developed and proposed for interference cancellation, mainly for radar scenarios where the direction of the signal of interest (SOI) is known a priori [7], [8]. The D3LS method has an advantage over the classical methods in the sense that it does not require training data and it is a single snapshot processing. That means there is no convergence issue for the D3LS. However, in communication scenarios, the direction of the SOI is usually not known, and the D3LS cannot be applied.

In this paper, the concept of the D3LS is presented to communication systems where the direction of the SOI is not known a priori. Instead, the method utilizes the knowledge of the training sequence in its weight calculation. It will be shown that the number of training sequence required is equal to the number of antennas in the array. Simulation results show that the proposed method can effectively suppress undesired signals and recover the desired one.

2. Direct Data Domain Least Squares (D3LS) Algorithm

In this section, a new D3LS algorithm is introduced to antenna array for interference rejection when the direction of the SOI is not known a priori. In stead of using the prior knowledge about the signal direction, the algorithm relies on the knowledge of the training sequence, which is usually the case in communication channel equalization [5]. Let us assume the transmitted training sequence be $\mathbf{s} = [s^0, s^1, \ldots, s^{N-1}]$ and the received signal at the *n*-th antenna and the *p*-th symbol time be defined as,

$$x_n^p = s^p e^{j2\pi\Delta(n-1)\cos\varphi_s} + v^p e^{j2\pi\Delta(n-1)\cos\vartheta_v}, \qquad \begin{array}{l} n = 0, \ldots, N-1 \\ p = 0, \ldots, N-1 \end{array} \tag{1}$$

where Δ is antenna element spacing, φ_s is the direction of the desired signal, v^p is the complex amplitude of the interfering signal, ϑ_v is the direction of the interference, and N is the number of antennas in the array.

As the knowledge of the training sequence is available at the receiver, we can define amplitude and phase difference between two consecutive sequences as $z^p = s^{p+1}/s^p$, where z^p represents the scaling factor between the *p*-th and (*p*+1)-th symbols. We then utilize the knowledge of z^p to create the cancellation equations as follows,

$$x_n^p z^p - x_n^{p+1} = \left(v^p z^p - v^{p+1}\right) e^{j2\pi\Delta(n-1)\cos\vartheta_v} \tag{2}$$

It is important to mention that the right hand side of (2) can be considered as a new interfering signal having the amplitude equals to $v^p z^p - v^{p+1}$ and arriving along the direction ϑ_v, which is the same as that of the original one in (1). We then create a $(N-1)\times N$ cancellation matrix by using (2) as,

$$\mathbf{F} = \begin{bmatrix} x_0^0 z^0 - x_0^1 & x_1^0 z^0 - x_1^1 & \cdots & x_{N-1}^0 z^0 - x_{N-1}^1 \\ x_0^1 z^1 - x_0^2 & x_1^1 z^1 - x_1^2 & \cdots & x_{N-1}^1 z^1 - x_{N-1}^2 \\ \vdots & \vdots & & \vdots \\ x_0^{N-2} z^{N-2} - x_0^{N-1} & x_1^{N-2} z^{N-2} - x_1^{N-1} & \cdots & x_{N-1}^{N-2} z^{N-2} - x_{N-1}^{N-1} \end{bmatrix}_{(N-1)\times N} \tag{3}$$

Noting that to form the cancellation matrix $\mathbf{F}$, we need to know neither the SOI nor the interference directions and $\mathbf{F}$ contains only the undesired signals. Only the knowledge of training symbols is required. A row of constraint equation, $\mathbf{c}$, is added to make (3) a square matrix as follows,

$$\begin{bmatrix} \mathbf{c} \\ \cdots \\ \mathbf{F} \end{bmatrix} \mathbf{w} = \begin{bmatrix} s^m \\ \cdots \\ \mathbf{0} \end{bmatrix} \tag{4}$$

where $\mathbf{c} = \begin{bmatrix} s^m & 0 & \cdots & 0 \end{bmatrix}$ and $\mathbf{w}$ is the weight vector to be determined. Since the information about the SOI direction is not available, the constraint can be only put on one antenna, which is the first antenna in this case. From (4), it is seen that $\mathbf{w}$ nulls the interfering signal. Since there is no constraint on other antennas, the solution experiences phase offset. The phase offset occurs as the result of the lacking of the SOI direction. However, we can compensate the phase offset by using the knowledge of the training sequence.

3. Simulation Results

To illustrate the proposed method, we simulate the signal received by a 5-element uniform linear array composing of ideal point sources. The SOI is a QAM 4-ary arriving along $\varphi_s = 140^\circ$. Two interference are simulated to be a QAM 4-ary signal arriving along $\vartheta_{v1} = 90^\circ$ and a QAM 16-ary signal arriving along $\vartheta_{v2} = 60^\circ$. The first five symbols of the SOI are assumed to be known at the receiver and are used to generate the cancellation matrix in (3). Once the weights are obtained, we use them to receive the SOI of 10,000 symbols. Figure 1 shows the beam pattern of the obtained weights. Figure 2 and 3 show the scatter plots of the received signals before and after applying the adaptive weights, respectively. It is seen in Figure 2 that the SOI is totally masked by the QAM 16-ary signal and it is recovered in Figure 3.

4. Conclusion

The paper presents a new technique based on the direct data domain least squares approach for interference suppression in communication system when the training sequence is assumed to be known. It is shown that once the weights are obtained, the method effectively nulls the interfering signals and the desired signal can be recovered. Since the method requires very small number of training sequence, it is a good candidate for real-time implementation.

References

[1] B. Widrow, P. E. Mantey, L. J. Griffiths, and B. B. Goode, “Adaptive Antenna Systems,” *Proc. IEEE*, vol. 55, no. 12, Dec 1967, pp. 2143-2159.

[2] S. Haykin, *Adaptive Filter Theory*, 4th ed., Prentice Hall, NJ, USA, 2001.

[3] I. S. Reed, J. D. Mallett, and L. E. Brennan, “Rapid Convergence Rate in Adaptive Arrays,” *IEEE Trans. Aerosp. Electron. Syst.*, vol. AES-10. no. 6, Nov. 1974, pp. 853-863.

[4] J. L. Volakis (ed.), *Antenna Engineering Handbook*, 4th ed., McGraw-Hill, USA, 2007.

[5] J. Boccuzzi, *Signal Processing for Wireless Communications*, McGraw-Hill, USA, 2008.

[6] A. Boonpoonga, P. Sirisuk, and M. Krairiksh, “A Switched-beam Element Phased Array Antenna for CMA Initialization,” *Proceedings of Microwave Conf. 2006*, Sep. 2006, pp. 772-775.

[7] T. K. Sarkar and N. Sangruji, “An adaptive Nulling System for a Narrowband Signal with a Look Direction Constraint Utilizing the Conjugate Gradient Method,” *IEEE Trans. Antennas and Propagation*, vol. 37, issue 7, July 1989, pp. 940-944.

[8] T. K. Sarkar, M. C. Wicks, M. Salazar-Palma, and R. J. Bonneau, *Smart Antennas*, John Wiley & Sons, Inc., NJ, USA, 2003.

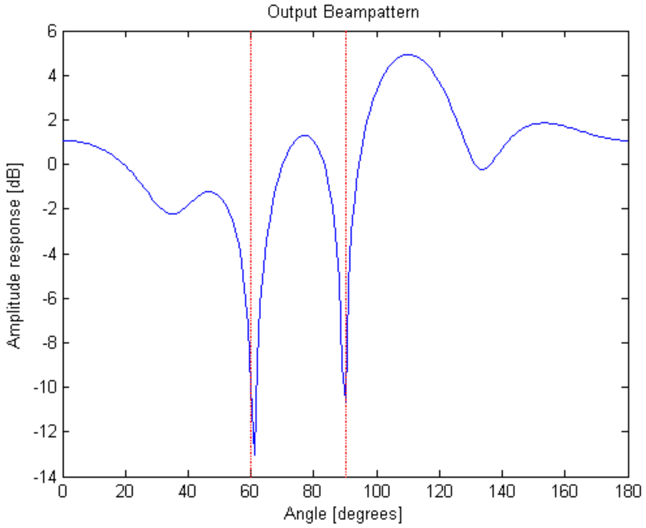

Figure 1 Beam pattern of the receiving array. The vertical lines indicate the directions of the interfering signals.

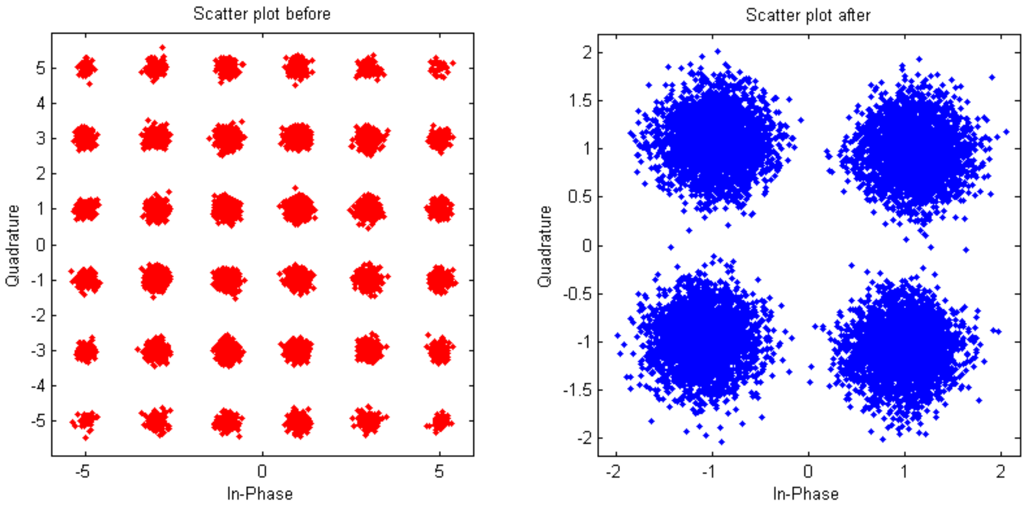

Figure 2 Scatter plots of the received signal before (left) and after (right) applying the adaptive weights.