Adaptive Block Size for Multistage LS-CMA Beamformer

D.Annalingam, F.H.Ali and E.Stipidis
Communications Research Group, School of Engineering and Information Technology
University of Sussex

1. Abstract

In this paper we examine multistage beamformer using Least Square Constant Modulus algorithm (LS-CMA) using fixed and adaptive block size to separate co-channel signals in multipath environment. Multistage CMA array is capable of capturing and separating several sources, where each stage consists of adaptive beamformer and an adaptive signal canceller. However it is shown here that using adaptive block size within the beamformer stage each source can be recovered faster, and the beamformer is much better at tracking the captured signal during short time fading, and thus reducing the error propagating through the subsequent stages. Computer simulation results to show the signal recovering properties of the LS-CMA beamformer for adaptive and fixed block size in a fading environment are presented.

2. Introduction

In wireless systems, transmitted signal do not simply propagate from the transmitter to receiver, but it gets scattered widely by objects within the environment it propagates. The received signal is the combination of delayed and attenuated versions of transmitted signal. Separation of Co-channel sources are becoming increasingly important since more frequencies are re-used due to the increase in number of cellular users and the need for higher capacity systems. It has been shown that using adaptive antenna array with multistage constant modulus array [1,2] is capable of separating several co-channel signals without the use of training signals. CMA is considered to be one of the popular blind adaptive algorithms because of its fast convergence properties and low computational complexity [3].

In multistage CM array, each stage consists of two main components an adaptive beamformer to capture a source and an adaptive signal canceller to remove the captured source so that in the next stage a different source can be recovered. Most CM array co-channel separators use stochastic gradient descent (SGD) form [3] to recover each source. The main drawback of SGD method is its slow convergence, a fast convergence version of CMA is Least Square CMA (LS-CMA) [4], since the error criterion is calculated from the average of desired response unlike the SGD methods. In [3] the issue of tracking the captured signal during fading is discussed, where decision direct approach is used to track the fading signal. In this paper we analyse the convergence of LS-CMA with adaptive step size for multistage CM array and the tracking of the captured signal during short time fading to reduce error propagation through later stages.

Section 3 presents an overview of the operations in multistage CM array and LS-CMA. Section 4 describes the adaptive block size calculations. Section 5 shows simulations results of adaptive block size LS-CMA compared with fixed block size, and section 6 concludes the paper.

3. Multistage Constant Modulus Array

When there are several sources received at the antenna array multistage CM array is used to extract each signal in a sequential manner. Each stage of multistage array consists of adaptive beamformer to capture a source, and adaptive signal canceller to remove the captured signal from the array inputs. Figure 1 illustrates a multistage constant modulus array. The received baseband signal assuming sampled at the mth antenna element can be written as

$$x_m(k) = \sum_{p=1}^{P} \sum_{l=1}^{L} a_{lp}(k) s_{lp}(k) + n(k) \qquad (1)$$

Where $a_{lp}(k)$ is the array response matrix corresponding to the l^{th} path of the p^{th} source $s_{lp}(k)$, $n(k)$ is additive white gaussian noise, P is the number of sources and L is the number of multipaths.

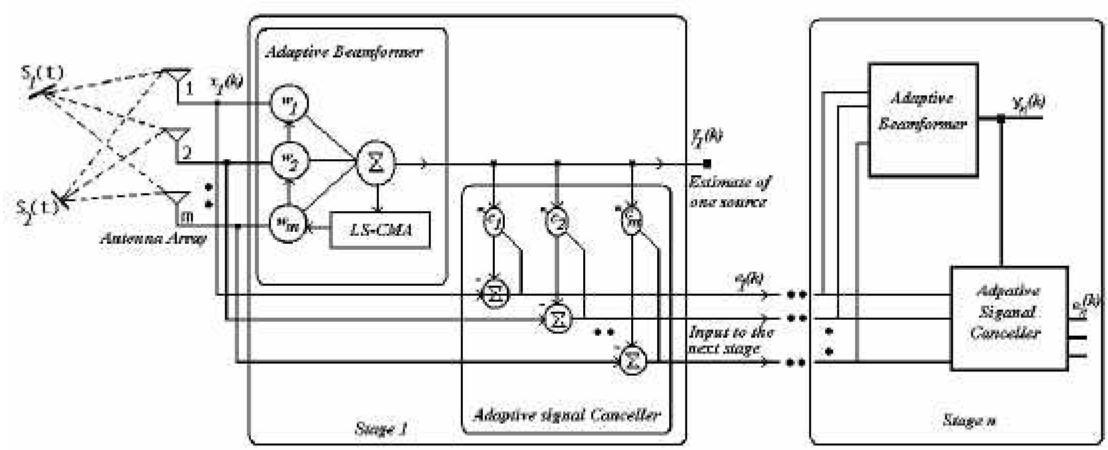


Figure 1 Multistage Constant Modulus Array

The estimate of one source at the beamformer output is given by

$$y(k) = w^H(k)x(k) \tag{2}$$

where $w^H(k)$ is the hermitian transpose of beamformer weight vector, $w(k) = [w_1(k), w_2(k)\ldots\ldots w_m(k)]$, and $x(k) = [x_1(k), x_2(k)\ldots\ldots x_m(k)]$. The new updated weight vector is calculated as,

$$w(k+1) = R_{xx}^{-1} r_{xd} \tag{3}$$

Given that R_{xx} and r_{xd} are

$$R_{xx} = \left\langle x(k)x^H(k) \right\rangle \tag{4}$$

$$r_{xd} = \left\langle x(k)d^*(k) \right\rangle \tag{5}$$

where < • > denotes the average over $N>0$ block size, * denotes complex conjugate and $d(k)$ the instantaneous modulus of the received signal given as,

$$d(k) = \frac{y(k)}{|y(k)|} \tag{6}$$

An adaptive signal canceller, removes the captured signal by weighting the output $y(k)$ with the canceller weights $c(k) = [c_1(k), c_2(k)\ldots\ldots c_m(k)]$, which is then subtracted from $x(k)$ to generate the input vector to the next stage and also be used to update the canceller weights as follows [3].

$$c(k+1) = c(k) + 2m_{step}y^*(k)e(k) \tag{7}$$

where $m_{step}>0$ is the step size and the input vector to the next stage $e(k)$ is calculated as

$$e(k) = x(k) - y(k)c(k) \tag{8}$$

4. Adaptive Block Size

LS-CMA is numerically stable for any values of block size N [4] and N is very similar to the step size of SGD algorithms. When the block size is small the convergence is faster than of larger block size but the cost of misadjustment error is higher. The criteria of LS-CMA to minimise the Mean Square Error (MSE) is given by

$$\left\langle \left| d(k) - w^H(k)x(k) \right|^2 \right\rangle \tag{9}$$

Using the MSE, block size of the LS-CMA can be adapted so that beamformer can converge faster. The initial block size for stage 1 ($N_{1,1}$) is determined by the MSE in dB for the initial signal estimate of the beamformer, which is same as the initial MSE.

$$N_{1,1} = \left| 20\log_{10} \left| d(1) - w^H(1)x(1) \right|^2 \right| \tag{10}$$

The initial block size value of stage 1 ($N_{1,1}$) is used to initialise the consecutive stages by simply adding 1 for every stage. A new block size for stage 1 is then calculated depending on the online calculations of the MSE for consecutive blocks given as.

$$N_{i+1,1} = N_{i,1} + b(mse_{i,1} - mse_{i-1,1})\,; \tag{11}$$

where i=1,2 3,……. Number of block sizes, b is a constant over each block assumed to be $\left|mse_{i,n}\right|$, $N_{i+1,1} > 0$, and the i^{th} mse is calculated as

$$mse_i = 20\log_{10}\left\langle \left|d(k) - w^H x(k)\right|^2 \right\rangle \tag{12}$$

In a multistage the n^{th} stage block size is calculated taking into account the pervious stage block size to further enhance the adaptation process of the block size; given by

$$N_{i+1,n} = N_{i,n-1} + b(mse_{i,n} - mse_{i-1,n})\,; \tag{14}$$

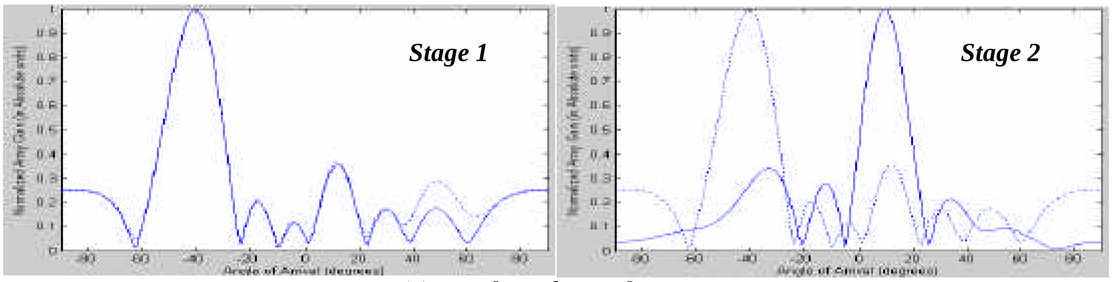
where n=2,3,4…….Number of stages and $N_{i+1,n-1} > 1$

5. Simulation and Results

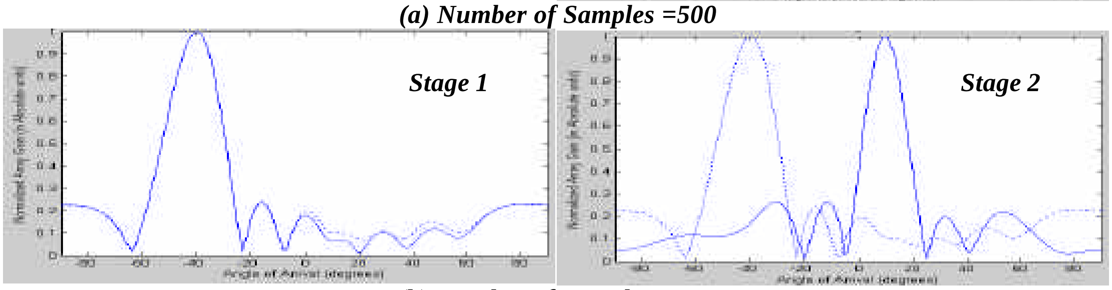
A two stage LS-CMA beamformer with adaptive signal canceller has been modelled using Matlab in multipath environment. The simulations assume that there are P=2 sources with L=2 multipaths for each source, and using a uniform antenna array with m=8 elements. The source signal is modulated using QPSK modulation, which undergoes Rayleigh fading with Signal to Noise Ratio (SNR) of 5dB. Table 1 shows the simulation parameters used for the results shown in figure 2 and 3.

	p=1 l=1	*p=1 l=2*	*p=2 l=1*	*p=2 l=2*
Gain (dB)	0	0	-1	-2
Delay (s)	0	1e-5	1e-5	2e-4
Angle of arrival (degree)	-40	-40	10	10

Table 1



(a) Number of Samples =500



(b) Number of Samples=1500

Figure 2 Response of Two Stage LS-CMA beamformer (solid line is Adaptive Block Size and dotted line is Fixed Block Size=50):

Figure 2 shows the beamformer response for adaptive and fixed block size. We can clearly see that the adaptive block size beamformer is capable of capturing both sources (source 1 in stage 1 and source 2 in stage 2) as shown in figure 2a. Further improvement of the adaptive block size beamformer response is also achieved by increasing the number of samples as shown in figure 2b. However with the fixed block size the response for stage 2 is still locked incorrectly on source 1.

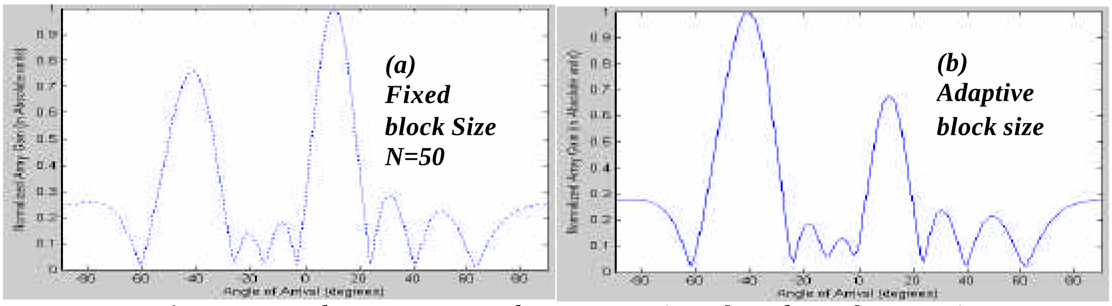


Figure 3 Beamformer Response from Stage 1 (number of samples =2500)

Figure 3 illustrates the effect of short-term fading where the amplitude of source 1 has gone smaller than source 2 after convergence. It is noted that the beamformer to converge and lock on a particular signal the captured signal's amplitude must be higher than that of the other signal present. It can be seen from figure 3a that the beamformer response is capturing the wrong source (in this case source 2 of the higher amplitude). However with the adaptive block size the beamformer is still locked on the correct converged signal of source1 despite the fact that it is of a smaller amplitude resulting in more robust system.

6. Conclusion

This paper presented multistage LS-CMA array with adaptive block size for signal separation. The block size is adapted using Mean Squared Error criteria. It is shown that the use of adaptive block size enables the beamformer to capture different sources faster than with fixed block size. It also shown with the proposed adaptive block size that once the beamformer has converged it can still lock on the captured signal even when the amplitude of the captured signal is smaller than that of the other signal present. This method gives more robust beamforming technique due to the better averaging of the estimated source during short term fading.

7. Reference

[1] J.J. Shynk A.V.Keerthi And A. Mathur, "Steady state analysis of the multistage CM array" IEEE Trans. On Signal Proc, vol 44, pp. 948-962, May 1996

[2] John J, Shynk and Richard P. Gooch "The Constant Modulus Array for CoChannel Signal Copy and Direction Finding" IEEE trans, on Signal Proc, Vol 44, No 3, pp 652-659, Mar 1996

[3] Srikanth Gummadi and Brain L. Evans "Cochannel Signal Separation in Fading Channel Using A Modified Constnat Modulus Array" *IEEE* Asilomar Conf on Signals, Systems, and Computers, Nov 1998

[4] Thomas E.Biedka, William H. Tranter and Jeffrey H. Reed "Convergence Analysis of the Least Squares Constant Modulus Algorithm" Proc of the Asilomar conf, on Signals, System, and Computers Nov 1996