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Stabilized Interference Suppression by Initial Antenna Selection for CMA Adaptive Array over Rayleigh Fading Channels

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Abstract—This paper proposes an antenna selective constant modulus algorithm (AS-CMA) to stabilize CMA's prominent interference suppression performance. CMA is well known blind adaptive array scheme, but it cannot suppress the interference when signal-to-interference power ratio (SIR) is smaller than 0 dB. It faces strong limits on their applicable region over Rayleigh fading channels where instantaneous channel gain fluctuates over 10 dB range. Even if the expected desired signal strength is larger than interference, CMA may still miscapture the interference and incorrectly suppress the desired signal. Our proposal is simplified approach to select the antenna element whose reception power is maximal. Certain antenna element can be expected to capture the desired signal precisely under the condition where SIR is statistically positive, so that the CMA processor can utilize it as an initial input. This condition will be ensured by increasing antenna element number, supported by the trends that base station antenna elements are going massive. Computer simulations verifies improved interference suppression performance provided by the proposed scheme.

1. Introduction

Array antenna signal processing is now widely implemented to commercial wireless communication systems such as LTE (-Advanced) and Wi-Fi. Most of these technologies requires a priori information such as channel state information (CSI) since interference channel is deterministic by system design. However, estimating CSI is based on known training signals which degrades resource utilization. Blind algorithms are quite effective in suppressing interference without any CSI estimation. Constant modulus algorithm (CMA) [1] [2] is well known and does not require any priori information such as a reference signal or direction of arrival. Lots of variables and their convergence characteristics have been widely investigated. Critical issues remain with CMA; it cannot suppress the interference when signal-to-interference power ratio (SIR) is smaller than 0 dB. It faces strong limits on their applicable region when the desired signal and the interference signal have around the same power. With Rayleigh fading channel environment, instantaneous channel gain fluctuates in over 10 dB range. Even if the expected desired signal strength is larger than interference signal, CMA may still miscapture the interference and incorrectly suppress the desired signal.

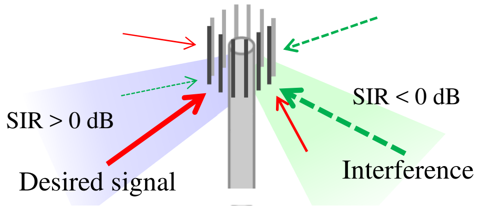

Figure 1: Concept of the proposed scheme.

Beam-space CMA (BSCMA) [3] is expected to compensate this drawback by giving initial weight which ensures to capture the desired signal. BSCMA can be interpreted as two-stage adaptive beamforming and interference suppression; fixed beam, eigenbeam [3] or maximal ratio combining (MRC) [4], etc. are available for the 1st stage beamforming and successive interference suppression is performed by CMA. Meanwhile, BSCMA involves twice adaptive array signal processing and it leads heavy computation complexity.

This paper proposes simplified approach to select the antenna element whose reception power is maximal. As illustrated in Fig. 1, certain antenna element can be expected to capture the desired signal precisely under the condition where SIR is statistically positive, so that the CMA processor can utilize it as an initial array input. This condition will be ensured by increasing the number of antenna elements. The trends in large-scale antennas being employed opens up its significance [5]. The rest of the paper is organized as follows. Sect. 2 and Sect. 3 describe the system model and brief summary of CMA, respectively. Sect. 4 presents the proposed scheme: antenna selective CMA (AS-CMA). Sect. 5 shows computer simulation results and Sect. 6 then concludes this paper.

2. System Model

In this paper, lowercase letters represent scalar quantities, bold letters indicate vectors or matrices, respectively. $|.|$, $(.)^T$, $(.)^H$, and $E[.]$ represent absolute value, transpose, conjugate transpose, and ensemble mean (expectation), respectively. Array antenna with Nr elements receives Nt

signals, one of which is a desired signal and the others are interference. Channel matrix, $\mathbf{H} \in \mathbb{C}^{Nr \times Nt}$, is represented as;

$$\mathbf{H} = \begin{pmatrix} h_{11} & h_{12} & \dots & & h_{1Nt} \\ h_{21} & \ddots & & & \\ \vdots & & h_{ij} & & \vdots \\ & & & \ddots & \\ h_{Nr1} & & \dots & & h_{NrNt} \end{pmatrix}, \tag{1}$$

where h_{ij} denotes the channel coefficient from the j-th transmitting antenna to the i-th receiving antenna element. It is given by an independent identically distributed (i.i.d) Rayleigh fading channel modeled as zero-mean complex Gaussian random variables with unit variance. In order to simulate the more practical channel environment, the i.i.d channel is converted into spatially correlated channel by introducing Kronecker model. Correlation matrix is given by $\mathbf{R} \in \mathbb{C}^{Nr \times Nr}$ and its component, r_{ij}, is defined based on simple exponential correlation matrix (ECM) model [6],

$$r_{ij} = \rho^{|i-j|}. \tag{2}$$

Let s_{jk} and x_{ik} denote the k-th ($1 \leq k \leq Ns$) symbol of the j-th ($1 \leq j \leq Nt$) transmission signal and the i-th ($1 \leq i \leq Nr$) reception signal, the composed signal vectors, $\mathbf{S} \in \mathbb{C}^{Nt \times Ns}$ and $\mathbf{X} \in \mathbb{C}^{Nr \times Ns}$, and their relationship can be expressed as,

$$\mathbf{X} = \mathbf{R}^{1/2}\mathbf{H}\mathbf{S} + \mathbf{N}. \tag{3}$$

$\mathbf{N} \in \mathbb{C}^{Nr \times Ns}$ indicates an additive white Gaussian noise (AWGN) vector. Transmitters are assumed to have a single antenna and be spatially decorrelated, hence, correlation matrix is applied to only receiver side.

3. Constant Modulus Algorithm (CMA)

$\mathbf{W}_{\mathrm{CMA}}(m) \in \mathbb{C}^{Nr \times 1}$ defined as the CMA weight vector at the m-th ($m = 0, 1, 2, ...$) iteration order. CMA adapts the array output signal, y_k, to yield a constant envelope by minimizing the following cost function;

$$\begin{aligned} Q(\mathbf{W}_{\mathrm{CMA}}(m)) &= E\left[\left|\,|y_k|^p - \sigma^p\right|^q\right] \\ &= E\left[\left|\left|\mathbf{W}^H_{\mathrm{CMA}}(m)\mathbf{X}\right|^p - \sigma^p\right|^q\right]. \end{aligned} \tag{4}$$

σ is a constant envelope value and generally takes the value of one. p and q are positive integers, and take a value of one or two, respectively. A number of algorithms were investigated to minimize (4). We employ least square CMA (LS-CMA) [2] which is known to exhibit superior convergence performance. When $p = 1$ and $q = 2$, LS-CMA weight, $\mathbf{W}_{\mathrm{CMA}}(m)$, is updated in the following manner;

$$\begin{aligned} \mathbf{W}_{\mathrm{CMA}}(m+1) &= \mathbf{W}_{\mathrm{CMA}}(m) - \left[\mathbf{X}\mathbf{X}^H\right]^{-1}\mathbf{X}\left(\mathbf{y} - \mathbf{d}\right)^H \\ &= \left[\mathbf{X}\mathbf{X}^H\right]^{-1}\mathbf{X}\mathbf{d}^H, \end{aligned} \tag{5}$$

$$\mathbf{d} = \begin{bmatrix} d_1 & \cdots & d_k & \cdots & d_{Ns} \end{bmatrix}, \ \ where \ \ d_k = \frac{\sigma}{|y_k|}y_k, \tag{6}$$

$$\mathbf{y} = \mathbf{W}^H_{\mathrm{CMA}}(m)\mathbf{X}, \tag{7}$$

$$\mathbf{W}_{\mathrm{CMA}}(0) = \begin{bmatrix} 1 & 0 & \cdots & 0 \end{bmatrix}^T. \tag{8}$$

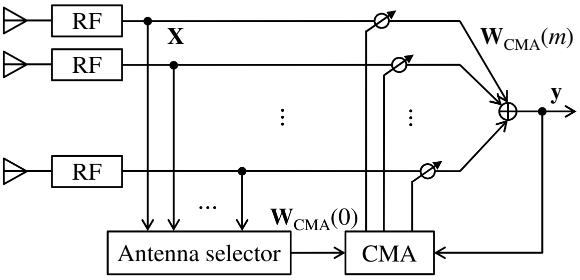

Figure 2: Configuration of the proposed scheme.

With the CMA, the desired signal must be captured at the initial array output. It indicates that the SIR of the initial array output must be larger than 0 dB.

Interference suppression performance of CMA strongly depends on initial weight in (8). One solution is to determine the initial weight by MRC [4];

$$\mathbf{W}_{\mathrm{MRC}} = \frac{1}{Ns}\mathbf{X}\mathbf{y}^H, \tag{9}$$

$$\mathbf{y} = \mathbf{W}^H_{\mathrm{MRC}}\mathbf{X}. \tag{10}$$

MRC emphasizes the desired signal strength but it does not perform interference suppression. Setting $\mathbf{W}_{\mathrm{CMA}}(0) = \mathbf{W}_{\mathrm{MRC}}$, iteration process in (5)–(7) can precisely suppress the residual interference signal. This paper define above scheme as MRC-CMA. It can be classified into one variants of BSCMA. Although this approach is effective to fully exploit CMA's ability, such two-stage adaptive signal processing enlarges the computation complexity.

4. Proposal: Antenna Selective CMA (AS-CMA)

Receiver configuration of the proposed scheme is depicted in Fig. 2. The major idea is to simply select the antenna element whose reception power is maximal.

$$c = \arg\max_i E\left[|x_{ik}|^2\right]. \tag{11}$$

$$\mathbf{W}_{\mathrm{CMA}}(0) = \begin{bmatrix} \delta_1 & \cdots & \delta_i & \cdots & \delta_{Nr} \end{bmatrix}^T$$

$$where$$

$$\delta_i = \begin{cases} 1 & (i = c) \\ 0 & (i \neq c) \end{cases}. \tag{12}$$

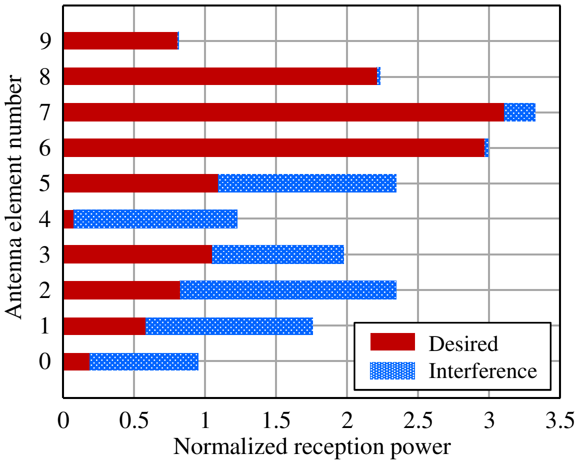

Figure 3: Example of reception power for each antenna element over Rayleigh fading channel (SIR = 6 dB).

It should be noted array input signal **X** includes desired and interference signals. Instantaneous SIR of each antenna elements fluctuates due to Rayleigh fading. AS-CMA exploits the expectation that largest receiving signal power is due to the desired signal if statistical SIR is positive.

Fig. 3 shows an example of two respective reception power for each antenna up to 10 elements. Channel coefficient is given by i.i.d Rayleigh fading and SIR is set to 6 dB. At the 7th antenna element shows the largest power in total and the desired signal is dominant, whereas some of other elements are dominated by interference signal. Fixedly providing an initial weight as in (8) fails to capture the desired signal and results in incorrect weight derivation. In this case, selecting the 7th antenna element, i.e. $\delta_7 = 1$ in (12), derives the optimal weight to extract the desired signal. Our proposal exploits this principle obtained in Rayleigh fading channel environment.

5. Computer Simulation

5.1. Simulation Parameters

Simulation parameters are listed in Table 1. Two incoming signals are assumed; one is the desired signal and the other is interference. Average SIR is set to 6 dB. Signal to noise and interference power ratio (SINR) of array output is used as evaluation metric. Since CMA is confirmed to work even in the multiple modulus signals, we examine behavior of the proposed scheme with 16QAM in addition to QPSK. Focusing on the performance of the proposed scheme, CMA parameters and symbol number are chosen to exhibit good convergence. Spatial correlation coefficient, ρ, is set to 0.573 in reference to the measurement result at 2.0 GHz with half wavelength antenna spacing [7]. Here compares three schemes; Conventional LS-CMA, MRC-CMA, and the proposed AS-CMA. We conducted 150,000 simulation trials with different channel origination.

Table 1: Simulation parameters

Parameter	Value	
Modulation	QPSK	16 QAM
Number of symbol	100	300
CMA iteration	20	100
Number of interference	1	
SNR	20 dB	
SIR	6 dB	
Channel model	i.i.d Rayleigh flat fading	
Spatial correlation	ECM model [6], $\rho = 0.573$ [7]	

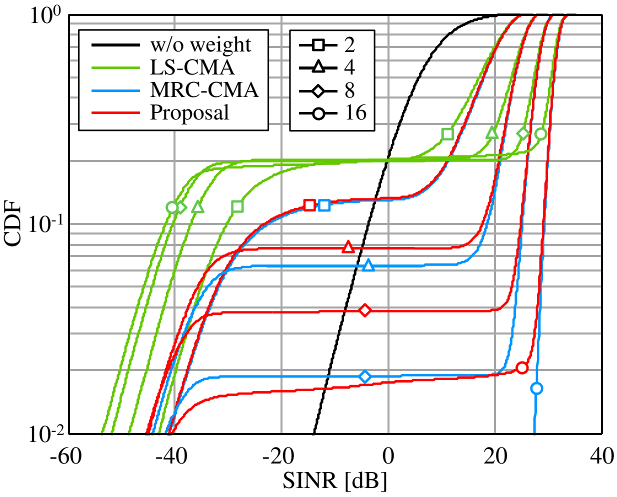

Figure 4: CDFs of SINR (QPSK).

5.2. Simulation Results

Cumulative distribution functions (CDFs) of SINR for QPSK case is plotted in Fig. 4 to observe an overall characteristics. Figure also plots SINR distribution of the case without interference suppression as a reference. Its median value corresponds to output SINR around 3 dB. For each scheme, here plots the cases with $Nr = 2$, 4, 8, and 16. Conventional LS-CMA largely improve output SINR when SIR > 0 dB whereas in the region SIR < 0 dB it suppresses the desired signal and the output is greatly deteriorated. The proposed AS-CMA can improve SINR performance compared to the conventional scheme. Selecting antenna can simply increases probability to capture the desired signal. The floor level is gradually reduced according to the increase of reception antenna elements, Nr. Although MRC-CMA achieves the best SINR performance, AS-CMA shows the approaching trend to that with simplified manner omitting calculation of (9) and (10).

Figs. 5 and 6 show SINR of CDF = 50% and CDF = 5% values with number of receiving antenna, respectively. Worst case CDF = 5% value exhibits the result with incorrect capture of interference and is independent to Nr. It can be improved at $Nr \geq 7$ by the proposed AS-CMA whereas $Nr \geq 5$ by the MRC-CMA. In the region, array gain of the

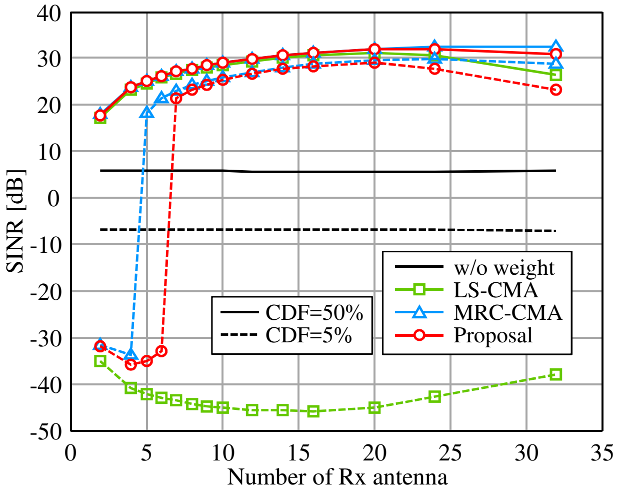

Figure 5: SINR versus number of Rx antenna (QPSK).

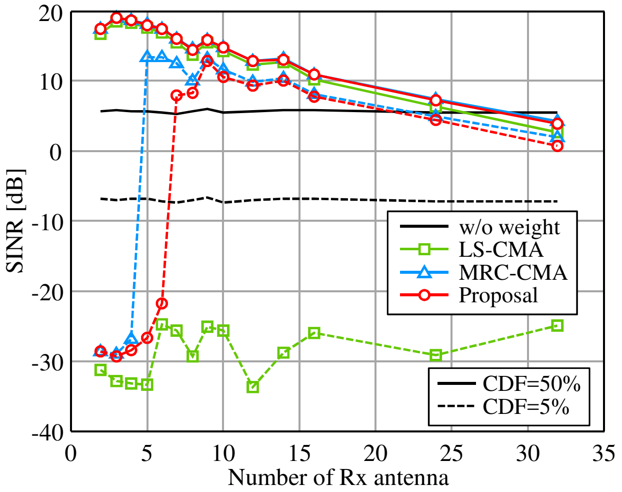

Figure 6: SINR versus number of Rx antenna (16QAM).

QPSK case is also precisely obtained by the factor of Nr. Improvement saturates and turns into diminution due to the noise enhancement caused by size growth of autocorrelation matrix, $\mathbf{XX}^H$. 16QAM case shows almost the same tendency. The proposed scheme does also work for multi modulus case although achievable SINR value is thought to be insufficient for 16QAM signal transmission. It requires increased symbol number and iteration to converge the CMA process for multi modulus signal. For more practical use, some modification would be required. Effectiveness of the proposed scheme should be further investigated incorporating with modified CMA (MCMA) [8].

6. Conclusion

This paper proposed simple antenna selective CMA to stably obtain the strong interference suppression ability of CMA over Rayleigh fading channels. Selecting one receiving antenna which has the largest power as initial array input increases the probability to capture the desired signal. Computer simulation confirmed its effectiveness that can improve worst-case SINR performance as increase of reception antenna element. Our proposal is a good match for the trend towards the large scale antenna systems.

Acknowledgments

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References

[1] J. Treichler, and B.G. Agee, “A new approach to multipath correction of constant modulus signals,” *IEEE Trans. Acoust., Speech, Signal Processs*, vol.31, no.2, pp.459–472, April 1983.

[2] B. Agee, “The least-squares CMA: A new technique for rapid correction of constant modulus signals,” *IEEE International Conference on Acoustics, Speech, and Signal Processing (ICASSP)*, pp. 953–956, April 1986.

[3] K. Nishimori, N. Kikuma, N. Inagaki, “The Differential CMA Adaptive Array Antenna Using an Eigen-Beamspace System,” *IEICE Trans., Commun.*, Vol.E78-B, No.11, pp.1480–1488, Nov. 1995.

[4] T. Tabata et al., “Experimental study of adaptive array antenna system for ISDB-T high speed mobile reception,” *2007 IEEE Antennas and Propagation Society International Symposium (APS)*, Honolulu, HI, pp. 1697–1700, June 2007.

[5] K. Nishimori, T. Hiraguri, T. Seki and H. Yamada, ”Multi-beam massive MIMO using analog beamforming and DBF based blind algorithm,” *2015 International Symposium on Antennas and Propagation (ISAP)*, Hobart, TAS, pp. 1–3, Nov. 2015.

[6] S. L. Loyka, “Channel capacity of MIMO architecture using the exponential correlation matrix,” in *IEEE Communications Letters*, vol. 5, no. 9, pp. 369–371, Sept. 2001.

[7] P. Alexis, A. García, and R. Lorenzo, “Frequency Dependent Indoor MIMO Channel Characterisation between 2 and 12 GHz Based on Full Spatial Correlation Matrices,” *Journal of Communications*, vol. 3, no.4, September, pp. 8–15, 2008.

[8] K. Banovic, E. Abdel-Raheem and M. A. S. Khalid, “Hybrid methods for blind adaptive equalization: new results and comparisons,” *10th IEEE Symposium on Computers and Communications (ISCC)*, pp. 275–280, June 2005.