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An OFDM Blind Adaptive Array Using Guard Interval with Eigen-Beamspace Preprocessor

Hayato Kaneyuki # Nobuyoshi Kikuma Yuichi Inami
Hiroshi Hirayama Kunio Sakakibara
Department of Computer Science and Engineering,
Nagoya Institute of Technology, Nagoya, 466-8555, Japan
E-mail:kikuma@nitech.ac.jp

1. Introduction

Service of one-segment broadcasting, which is a new type of the terrestrial digital TV broadcasting, began in Japan in April, 2006, and its use in mobile phones and car navigation equipments is attracting nationwide attention. It is known that the OFDM(Orthogonal Frequency Division Multiplexing) transmission technology is used in the terrestrial digital TV broadcasting and wireless LAN. The features of OFDM are high efficiency of frequency utilization and also effective use of FFT as a modulation scheme. In addition, a guard interval(GI) is inserted into the head of each OFDM symbol to overcome the delay spread of the channel. Hence, the communication performance of OFDM is superior to that of a single carrier in a multipath environment where the delay times of multipath waves are within GI.

However, inter-carrier interference is caused by incidence of multipath waves with delay time beyond GI or Doppler shift at mobile reception, which results in serious degradation in the OFDM transmission performance. For suppressing the inter-carrier interference, beam-forming and null-steering techniques by adaptive array antennas have been investigated [1]–[3]. As one of them, the MMSE(Minimum Mean Square Error) adaptive array utilizing the GI in OFDM was proposed which is a blind adaptive processor of pre-FFT type [2].

In this paper, we introduce the eigen-beamspace preprocessor into the MMSE adaptive array presented in [2] to improve the convergence characteristics. Furthermore, we attempt to use the differential CMA(Constant Modulus Algorithm) criterion, which also is a blind algorithm, in place of MMSE in the system. Via computer simulation, the performances of the proposed blind adaptive systems are clarified.

2. Eigen-Beamspace System and Signal Model

Suppose that a K-element array antenna receives $L(L \leqq K)$ multipath waves whose directions of arrival are different from each other. Figure 1 shows the eigen-beamspace adaptive array system utilizing the GI in OFDM. From K array element signals, through BFN(Beam-Forming Network), we have L beams(channels) for the adaptive processor. Here, the array element signals $x_1(t), \cdots, x_K(t)$, the beam outputs $b_1(t), \cdots, b_L(t)$, and weights $w_1, \cdots, w_L$ are expressed respectively in a vector form as follows:

$$\boldsymbol{X}(t) = [x_1(t), x_2(t), \cdots, x_K(t)]^T \tag{1}$$

$$\boldsymbol{B}(t) = [b_1(t), b_2(t), \cdots, b_L(t)]^T = E_S^H \boldsymbol{X}(t) \tag{2}$$

$$\boldsymbol{W} = [w_1, w_2, \cdots, w_L]^T \tag{3}$$

where E_S is the transformation matrix of BFN, and the superscripts T and H represent the transpose and the complex conjugate transpose, respectively. Then, the combined array output $y(t)$ is given by

$$y(t) = \boldsymbol{W}^H \boldsymbol{B}(t) = \boldsymbol{W}^H E_S^H \boldsymbol{X}(t) \tag{4}$$

In the eigen-beamspace system, the matrix E_S is composed of L eigenvectors belonging to signal subspace of the correlation matrix $R_{xx} \equiv E[\boldsymbol{X}(t)\boldsymbol{X}^H(t)]$, in which $E[\cdot]$ represents the expectation.

In Fig.1, CHOP-H and CHOP-T stand for signal extraction during the head guard interval(Head GI) and during the tail guard interval(Tail GI), respectively, of the desired OFDM signal(synchronized

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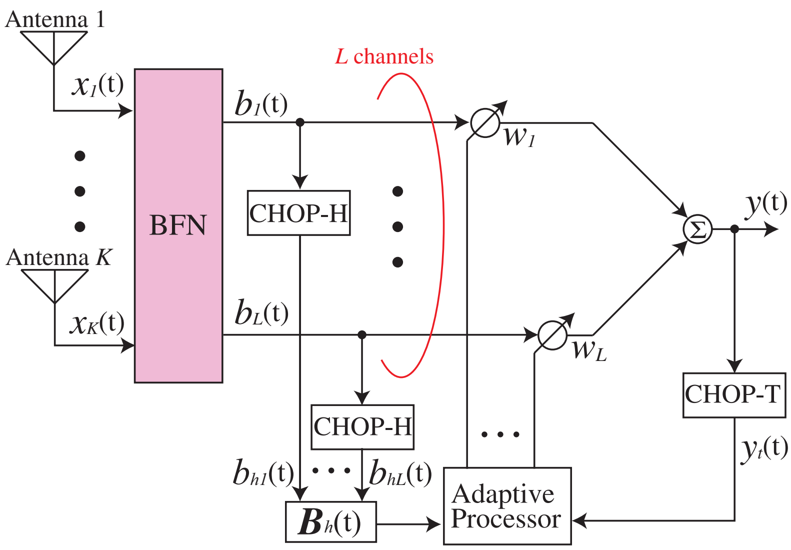


Figure 1: Eigen-beamspace adaptive array system utilizing GI in OFDM(K elements and L beams).

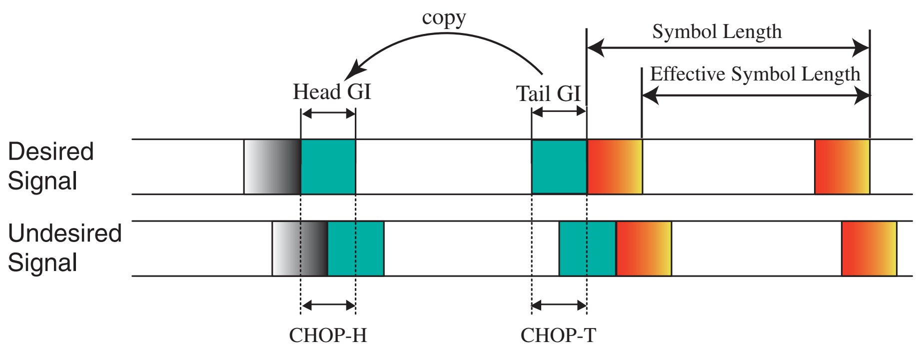


Figure 2: Relation between guard intervals of the desired and undesired signals.

signal). This is depicted in Fig.2 which shows the OFDM signal(desired signal) along with the delayed signal(undesired signal) in time domain. The beam outputs extracted by CHOP-H are expressed as $b_{hk}(t)$ ($k = 1, 2, \cdots, L$). Similarly, let $b_{tk}(t)$ ($k = 1, 2, \cdots, L$) express the ones extracted by CHOP-T. They are expressed respectively in a vector as follows:

$$\boldsymbol{B}_h(t) = [b_{h1}(t), b_{h2}(t), \cdots, b_{hL}(t)]^T \quad (5)$$

$$\boldsymbol{B}_t(t) = [b_{t1}(t), b_{t2}(t), \cdots, b_{tL}(t)]^T \quad (6)$$

In addition, we have the following relations.

$$\boldsymbol{B}_h(t) = E_S^H \boldsymbol{X}_h(t), \quad \boldsymbol{B}_t(t) = E_S^H \boldsymbol{X}_t(t), \quad y_h(t) = \boldsymbol{W}^H \boldsymbol{B}_h(t), \quad y_t(t) = \boldsymbol{W}^H \boldsymbol{B}_t(t) \quad (7)$$

where $\boldsymbol{X}_h(t)$ and $\boldsymbol{X}_t(t)$ are element signal vectors extracted from $\boldsymbol{X}(t)$ by CHOP-H and CHOP-T, respectively.

3. Optimization Algorithms

Head GI and Tail GI are identical in the OFDM symbol as shown in Fig.2. Using this feature, we determine the weight vector $\boldsymbol{W}$ on a criterion of MMSE or differential CMA(DCMA).

3.1 Algorithm based on MMSE

Using $y_t(t)$ as a reference signal for MMSE, the cost function which is minimized with respect to $\boldsymbol{W}$ is expressed as

$$Q_{\mathrm{MMSE}}(\boldsymbol{W}) = E\left[\left|\boldsymbol{W}^H \boldsymbol{B}_h(t) - y_t(t)\right|^2\right] \quad (8)$$

Table 1: Simulation conditions.

modulation scheme	64QAM
number of carriers	1405
effective symbol length	2048 samples
GI	128 samples
array configuration	4-element uniform linear array
element spacing	half wavelength of center frequency
number of waves	2
CNR	25dB

Table 2: Radio environment.

	wave 1(Desired)	wave 2(Undesired)
DOA from array broadside	30 deg	−60 deg
delay time	—	50 samples
DUR	—	5dB

Thus, the SMI(Sample Matrix Inversion)-based algorithm to update recursively $\boldsymbol{W}$ is given by

$$\boldsymbol{W}(m) = \left\{E_S^H(m)E\left[\boldsymbol{X}_h(m)\boldsymbol{X}_h^H(m)\right]E_S(m)\right\}^{-1} E_S^H(m)E\left[\boldsymbol{X}_h(m)\boldsymbol{X}_t^H(m)\right]E_S(m-1)\boldsymbol{W}(m-1) \tag{9}$$

where m is the iteration number equal to symbol number and $E[\cdot]$ means time average during the GI. Also, $E_S(m)$ is derived from the matrix $E[\boldsymbol{X}_h(m)\boldsymbol{X}_h^H(m)]$.

3. 2 Algorithm based on differential CMA

The cost function based on differential CMA(DCMA), which is minimized, is expressed as

$$Q_{\mathrm{DCMA}}(\boldsymbol{W}) = E\left[\left||y_h(t)| - |y_t(t)|\right|^2\right] \tag{10}$$

Another expression using explicitly $\boldsymbol{W}(m)$ is given by

$$Q_{\mathrm{DCMA}}(\boldsymbol{W}(m)) = E\left[\left||\boldsymbol{W}^H(m)E_S^H(m)\boldsymbol{X}_h(m)| - |\boldsymbol{W}^H(m)E_S^H(m)\boldsymbol{X}_t(m)|\right|^2\right] \tag{11}$$

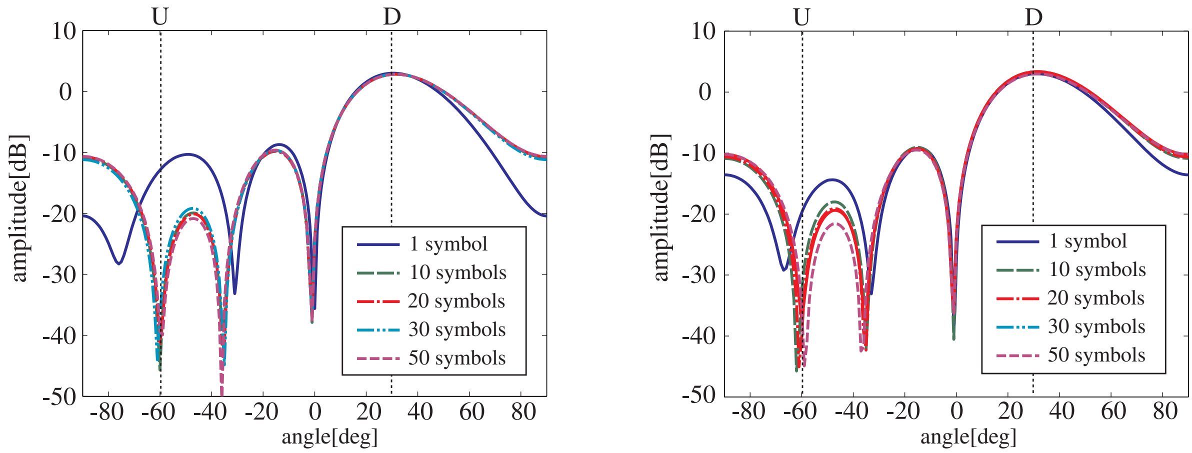
Since eq.(11) has the trivial solution $\boldsymbol{W}(m) = \boldsymbol{0}$, the condition $w_1 = 1$ is imposed on the minimization to exclude it. Also, eq.(11) is nonlinear with respect to $\boldsymbol{W}(m)$, and so we employ here the Gauss-Newton method to obtain the optimum weight vector. In this paper, the optimum weight vector obtained at the mth symbol is recursively used as the initial vector for the Gauss-Newton method at the next $(m+1)$th symbol.

4. Computer Simulation

The performances of eigen-beamspace MMSE and DCMA adaptive arrays for OFDM are analyzed through computer simulation. Tables 1 and 2 show the simulation conditions and radio environment, respectively. It is assumed that two incoming waves are plane wave with no fading and that symbol and frequency synchronization to the desired signal(wave 1) is completely performed. The initial weight vector is $\boldsymbol{W}(0) = [1, 0, 0, 0]^T$. In the Gauss-Newton method of DCMA, the number of iterations per symbol is limited to 8.

Figures 3(a) and 3(b) show the directional patterns from 1 to 50 symbols by eigen-beamspace MMSE and DCMA, respectively. It is observed that both systems converge to the optimum state with a null in the direction of wave 2 after 10 symbols.

Figure 4 demonstrates their convergence characteristics which are the relations between the output SINR(signal-to-interference-plus-noise ratio) and the number of symbols. Compared with the element-space MMSE, the eigen-beamspace MMSE and DCMA attain high SINRs over 20dB and 25dB, respectively, at the first symbol. Particularly, it is found that eigen-beamspace DCMA achieves the good performance at the first symbol. This is because the iteration number of 8 is enough for the Gauss-Newton method in DCMA. It can be expected that the convergence rate of the eigen-beamspace MMSE



(a) MMSE (b) DCMA

Figure 3: Directional patterns by eigen-beamspace OFDM adaptive arrays.

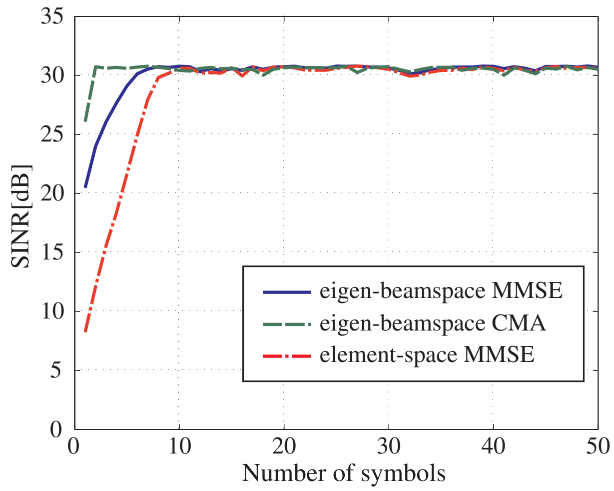


Figure 4: SINR convergence characteristics of OFDM adaptive arrays.

will also be raised when similarly repeating the weight update of eq.(9) for each symbol. This is our future work.

5. Conclusion

The performances of the MMSE and differential CMA(DCMA) adaptive arrays with the eigen-beamspace preprocessor have been examined in the OFDM transmission. As a result of computer simulation, it is shown that both proposed adaptive arrays attain fast convergence and stable characteristics of high SINR in comparison with the conventional element-space MMSE.

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