Initial Weights for Improving Convergence Characteristics in Mobile Reception of the MMSE Adaptive Array for OFDM Transmission

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1. Introduction

It is known that the OFDM (Orthogonal Frequency Division Multiplexing) transmission technology is used in the terrestrial digital TV broadcasting and wireless LAN. The OFDM is featuring high efficiency of frequency utilization and also effective use of FFT in the 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 multipath environments where the delay times of multipath waves are within the GI length.

On the other hand, inter-carrier interference is caused by incidence of multipath waves with delay times exceeding the GI length or by Doppler shift in the mobile reception environment, which results in serious degradation in the OFDM transmission performance. As one of techniques for suppressing the interference, the MMSE (Minimum Mean Square Error) adaptive array utilizing the GI in OFDM (GI-MMSE) was proposed which is a blind adaptive processor of pre-FFT type [2]. However, due to the blind processing, the improvement of the convergence characteristics of the adaptive system remains to be addressed [3].

In this paper, we consider the way of giving the initial weights to the GI-MMSE in the mobile reception for improving the convergence characteristics. Through computer simulation, we demonstrate how significantly convergence characteristics of the GI-MMSE adaptive array are improved by the proposed methods of making the initial weights.

2. 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. Let $x_1(t), \cdots, x_K(t)$ represent the array element signals and $w_1, \cdots, w_K$ the array weights. They normally are expressed in vector form as $\boldsymbol{X}(t) = [x_1(t), x_2(t), \cdots, x_K(t)]^T$ (array input vector) and $\boldsymbol{W} = [w_1, w_2, \cdots, w_K]^T$ (weight vector) , respectively. Then, the combined array output $y(t)$ is given by $y(t) = \boldsymbol{W}^H \boldsymbol{X}(t)$.

Figure 1 shows the OFDM signal (desired signal) along with the delayed signals (undesired signals) in time domain, which is in the case of $L = 3$. From the array element signals, we extract two signals, one is during the head guard interval (Head GI) and the other is during the tail guard interval (Tail GI) of the desired signal that is a synchronized signal. Those extracted head and tail signals are represented as $\boldsymbol{X}_h(t)$ and $\boldsymbol{X}_t(t)$ in vector form, respectively.

3. Initial Weights for Improving Convergence Characteristics

3. 1 Method of Using Power Inversion Criterion

This method makes a use of differential signal between Head GI and Tail GI. Due to the agreement of the desired signal components in Head GI and Tail GI, the desired signal component is not included in the GI differential signal. The power inversion (PI) criterion [1] is applied to the GI differential signal in order to obtain array weights which suppress all delayed signals at the array output.

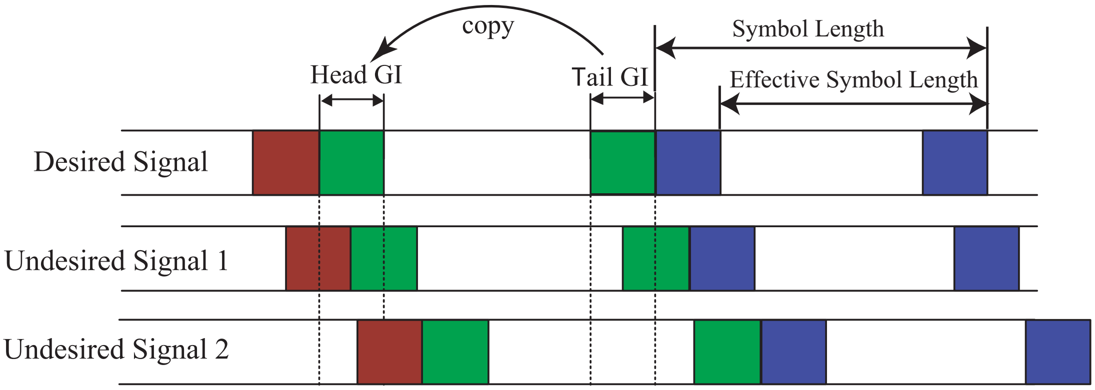

Figure 1: Relation between guard intervals of the desired and undesired signals.

Therefore, the initial weight vector of this method is given by

$$\boldsymbol{W}_{PI} = \boldsymbol{R}_{dd}^{-1}[1,0,0,\cdots]^T \tag{1}$$

$$\boldsymbol{R}_{dd} = E\left[(\boldsymbol{X}_h(t) - \boldsymbol{X}_t(t))(\boldsymbol{X}_h(t) - \boldsymbol{X}_t(t))^H\right] \tag{2}$$

where $\boldsymbol{R}_{dd}$ is the correlation matrix of the GI differential signal and $E[\cdot]$ means the expected value.

3.2 Method of Using Eigenvector of Minimum Eigenvalue

The initial weight vector of this method is represented as

$$\boldsymbol{W}_{ME} = \boldsymbol{e}_d \tag{3}$$

where $\boldsymbol{e}_d$ is the eigenvector corresponding to the minimum eigenvalue of $\boldsymbol{R}_{dd}$. This weight vector steers deep nulls in the directions of all delayed signals.

3.3 Method of Using Capon and DCMP

In this method, utilizing Capon method [1], we estimate θ_s, DOA of the desired signal, from the angle maxmizing the following angle spectrum:

$$P(\theta) = \frac{\boldsymbol{a}^H(\theta)\boldsymbol{R}_{dd}^{-1}\boldsymbol{a}(\theta)}{\boldsymbol{a}^H(\theta)\boldsymbol{R}_{xx}^{-1}\boldsymbol{a}(\theta)}, \quad \boldsymbol{R}_{xx} = E\left[\boldsymbol{X}_h(t)\boldsymbol{X}_h(t)^H\right] \tag{4}$$

where $\boldsymbol{R}_{xx}$ is the correlation matrix of the Head GI signal, and $\boldsymbol{a}(\theta)$ is the array response vector (mode vector) [3]. To obtain the initial weight, we use DCMP method [1] as shown below.

$$\boldsymbol{W}_{CD} = \frac{\boldsymbol{R}_{xx}^{-1}\boldsymbol{C}}{\boldsymbol{C}^H\boldsymbol{R}_{xx}^{-1}\boldsymbol{C}} \qquad \left(\boldsymbol{W}^H\boldsymbol{C} = 1,\ \boldsymbol{C} = \boldsymbol{a}(\theta_s)\right) \tag{5}$$

4. Performance Analysis by Computer Simulation

Through computer simulation, we carry out the performance analysis of GI-MMSE adaptive array to examine the effectiveness of the initial weight vectors above-mentioned. Tables 1 and 2 show the simulation conditions and radio environment, respectively. It is assumed that three plane waves are incoming with no fading and also that symbol and frequency synchronization to the desired signal (wave 1) is completely performed. T_e is the effective symbol length.

First, we confirm the angle spectrum of Eq.(4), which is expected to provide the DOA estimation of desired signal by Capon method. Figure 2 shows the DOA estimation of the desired signal in the fixed reception environment (Doppler frequency = 0). It is observed in the figure that the maximum peak direction agrees with the DOA of the desired signal. On the other hand, Figure 3 shows the DOA estimation of the desired signal in the mobile reception. Although the noise level of angle spectrum is

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
antenna element	isotropic antenna
element spacing	half wavelength of center frequency
number of waves	3
CNR	25 dB
Doppler frequency	0 (fixed) , 0.05 / T_e (mobile)

Table 2: Radio environment.

	wave 1 (Desired)	wave 2 (Undesired)	wave 3 (Undesired)
DOA from array broadside	0 deg	−60 deg	30 deg
delay time	—	48 samples	144 samples
DUR	—	5 dB	15 dB

higher than Fig. 2, it can be seen that the DOA of the desired signal is estimated successfully from the maximum peak direction.

Next, we compare the initial directional patterns formed by the three methods. Figure 4 shows the initial directional patterns in the fixed reception. It is found that all methods suppress only undesired signals. Also, Figure 5 shows the initial directional patterns in the mobile reception. It is seen that the desired signal is suppressed as well as the undesired signals in the cases of using PI method and eigenvector method. On the other hand, the desired signal can be preserved by Capon-DCMP method.

Finally, the convergence characteristics of output SINR are compared. In addition to the three methods, an isotropic pattern as the initial pattern is taken into this comparison. Figure 6 shows the convergence characteristics of SINR in the fixed reception. It is seen that SINRs of the three proposed methods are already stable after the first symbol. Figure 7 shows the convergence characteristics of SINR in the mobile reception. It is seen that only Capon-DCMP method can attain high SINR at the early stage and hence improve the convergence characteristics. It means that Capon-DCMP method is superior in the mobile reception environments.

5. Conclusion

The initial weights of the MMSE adaptive array using the guard interval in OFDM signal have been examined. PI method and eigenvector method can improve the convergence characteristics in the fixed reception. However, the two methods deteriorate in the mobile reception. Capon method using the GI differential signal can estimate DOA of desired signal in both fixed reception and mobile reception. Thus, Capon-DCMP method can improve the convergence characteristics in the mobile reception as well as in the fixed reception. As the future work, we will investigate the further improvement of convergence characteristics of the GI-MMSE adaptive array.

References

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[2] S. Hori, N. Kikuma, and N. Inagaki: “Study on Initial Values of Optimization Algorithm for an MMSE Adaptive Array Utilizing Guard Interval in OFDM Signal (in Japanese),” IEICE Trans. Commun., vol.J88-B, no.9, pp.1821–1824, Sept. 2005.

[3] S. Hori, N. Kikuma, and N. Inagaki: “DOA Estimation to Direct Synchronized Signal in the OFDM Systems under Multipath Environments (in Japanese),” IEICE Trans. Commun., vol.J87-B, no.9, pp.1397–1404, Sept. 2004.

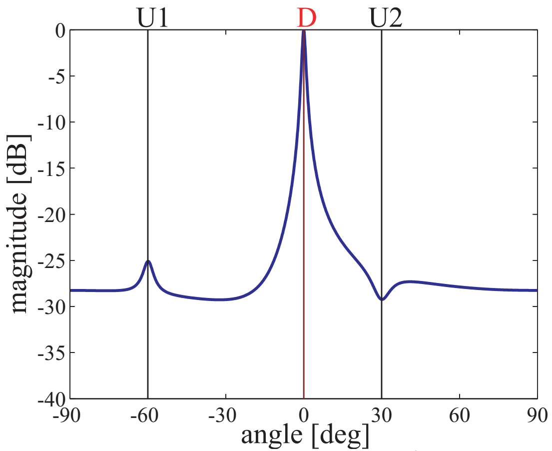

Figure 2: Angle spectrum of Capon
in fixed reception.

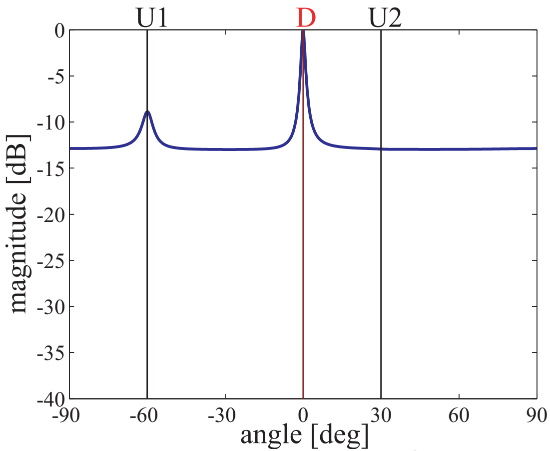

Figure 3: Angle spectrum of Capon
in mobile reception.

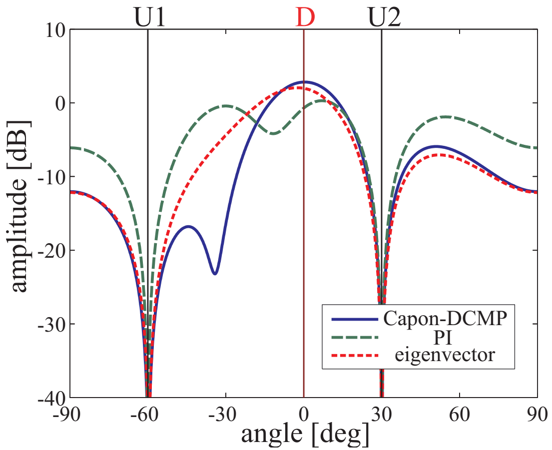

Figure 4: Initial directional patterns
in fixed reception.

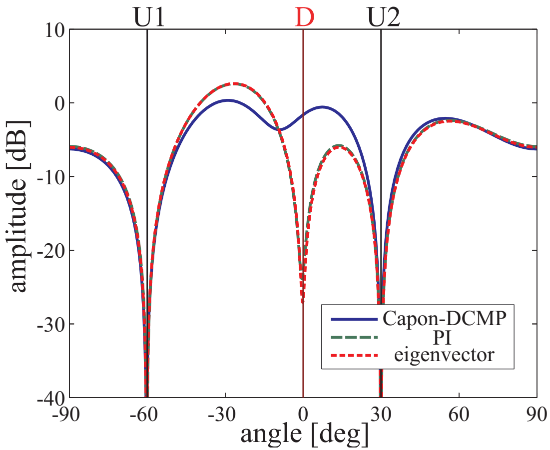

Figure 5: Initial directional patterns
in mobile reception.

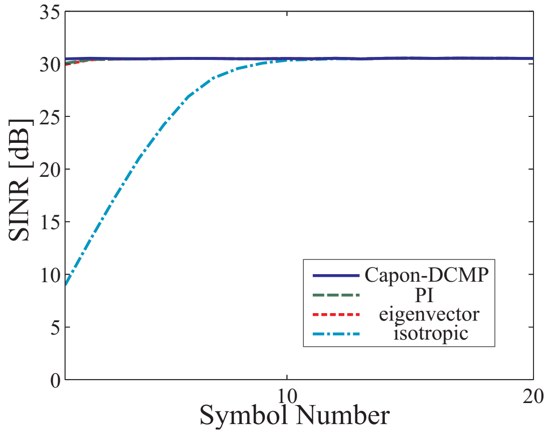

Figure 6: SINR convergence characteristics
in fixed reception.

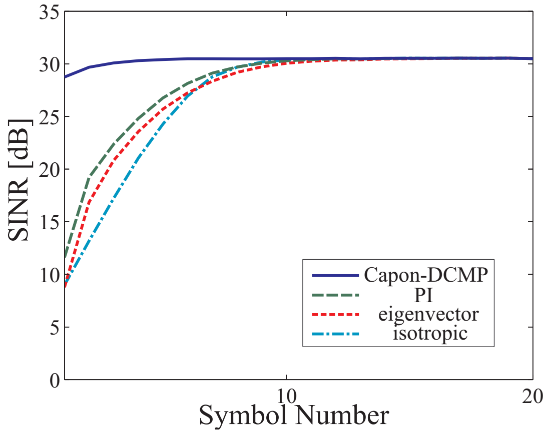

Figure 7: SINR convergence characteristics
in mobile reception.