

A Convergence Acceleration Technique for a Blind 2D-RAKE Receiver based on CMA criteria

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1 Introduction

RAKE^[1] is a key technology of Direct-Sequence Spread Spectrum (DS/SS) systems in order to overcome multipath fading by combining delayed signals. It can be extended over the space domain with a combination of an array antenna so called as two-dimensional (2D) RAKE. However, it should be noted that it requires the bit timing prior to the RAKE combining. It means that RAKE combining cannot be performed under low-SN or severe fading environment in which the initial bit timing cannot be acquired.

In order for solving this problem, an asynchronous blind 2D-RAKE technique based on the CMA criteria has been proposed^[2]. Although it solves the problem, the convergence for deriving the weights takes relatively long time since it employs a number of weights.

In this paper, aiming at improving the convergence speed and the stability of the blind 2D-RAKE method proposed in [2], we propose a convergence acceleration technique. It is expected that the acceleration technique improves not only the convergence speed but also the output SNR.

The rest of the paper is organized as follows. In the Section 2, signals and the blind 2D-RAKE are formulated. Then, in Section 3, the proposed acceleration technique is proposed. After that, in Section 4, the performance is verified through computer simulations. Finally, this paper is concluded in Section 5.

2 Formulations

Figure 1 illustrates a receiver configuration of the proposed scheme equipped with L antennas^[2]. The received signals by the antennas are expressed by a vector $\mathbf{x}(t)$ of size $(L \times 1)$ as follows:

$$\mathbf{x}(t) = \sum_{m=1}^M c_m \mathbf{a}(\theta_m) s(t - \tau_m) + \boldsymbol{\eta}(t) \tag{1}$$

where θ_m , c_m and τ_m denote the direction of arrival (DOA), the complex amplitude and the delay of the m -th multipath ray, respectively. $\mathbf{a}(\theta_m)$ and $s(t)$ are the steering vector $(L \times 1)$ and the DS-SS modulated signal by using a PN code of length N , respectively. $\boldsymbol{\eta}(t)$ is a noise vector $(L \times 1)$. $\mathbf{x}(t)$ is frequency-converted by RF front-ends (RF F/E) and sampled in the duration T_s . This yields $\mathbf{x}[h] = \mathbf{x}(hT_s)$ where h is an integer. For simplicity, let us focus on the ℓ -th ($\ell = 1, \dots, L$) antenna output $x_\ell[h]$, i.e., ℓ -th component of $\mathbf{x}[h]$. $x_\ell[h]$ is first fed into the matched filter working as the sliding correlator and let $x_{MF,\ell}[h]$ denote the matched filter output. Then, this is stored in tapped delay lines consisting of αN taps connected to the antennas as the following of size $(\alpha N \times 1)$. Here, α is an integer more than 1. Hereafter, for facilitating understanding, α is set as 1.

$$\mathbf{b}_{TDL,\ell}[h] = [x_{MF,\ell}[h], x_{MF,\ell}[h-1], \dots, x_{MF,\ell}[h-N+1]]^T \tag{2}$$

Then, these stored samples are downsampled with the bit rate T_b . Therefore,

$$\mathbf{b}_{DS,\ell}[k] = \mathbf{b}_{TDL,\ell}[h + \nu]_{h=kT_b/T_s} \quad (3)$$

where ν denotes the unknown time offset since it is assumed that the bit timing is unknown. k is an integer. Accordingly, the rate of samples is downsampled from the chip rate to the bit rate. Finally, the output is obtained as follows:

$$y[k] = \mathbf{W}^H \mathbf{B}_{DS}[k] \quad (4)$$

where

$$\mathbf{W} = [\mathbf{w}_1 \quad \mathbf{w}_2 \quad \cdots \quad \mathbf{w}_L]^T, \quad \mathbf{w}_\ell = [w_{\ell,1} \quad w_{\ell,2} \quad \cdots \quad w_{\ell,N}], \quad \ell = 1, \dots, L \quad (5)$$

$$\mathbf{B}_{DS}[k] = [\mathbf{b}_{DS,1}^T[k] \quad \mathbf{b}_{DS,2}^T[k] \quad \cdots \quad \mathbf{b}_{DS,L}^T[k]]^T \quad (6)$$

The weight vector is estimated using CMA criteria through the steepest descent method iteratively as:

$$\mathbf{W}[k+1] = \mathbf{W}[k] - 4\mu \mathbf{B}_{DS}[k] y[k] (|y[k]|^2 - \sigma^2) \quad (7)$$

where μ and σ is the step size and a constant.

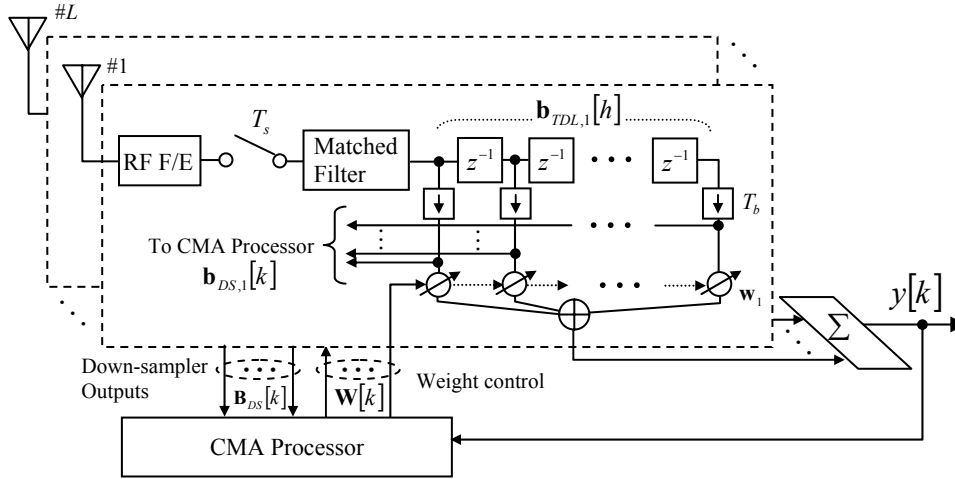


Figure 1 A receiver configuration based on the proposed scheme.

3 Proposed Scheme

Although the above-mentioned scheme achieves 2D-RAKE asynchronously, it takes relatively long time to estimate \mathbf{W} since it consists of a number of weights.

Now, a numerical example is given for the sake of showing the behavior of the scheme explained in Section 2. Table 1 lists the simulation conditions.

Table 1 Simulation Conditions

| | |
|--|--|
| PN code (Spreading code) length (N) | M-sequence, $N=31$ |
| TDL length (N) | 31 |
| Antenna and the number of elements (L) | 8-element half wavelength-spaced linear array |
| The number of multipath signals (M) | 2 |
| Delay and offset of multipath signals ($\tau_m + \nu$) | $\tau_1 + \nu = 17$ [chip], $\tau_2 + \nu = 27$ [chip] |
| Direction of Arrival (θ_m) | $\theta_1 = -20$ [deg], $\theta_2 = 30$ [deg.] |
| Input SNR | 0 dB/element for all multipath signals |
| CMA parameters | $\mu = 15 \times 10^{-6}$, $\sigma = 100$ |

Note that, according to the simulation conditions, we obtain the output signal-to-noise ratio (SNR) 12dB since 0dB/element + 9dB (antenna gain) + 3dB (by combining the 2 rays) = 12dB. Figure 2 shows the absolute value of 31 components of \mathbf{w}_1 obtained after 300 iterations. The absolute values are normalized by the largest value among them. It is clearly seen that the weights corresponding to the delay of the 2 rays yield large amplitude. Now, let us define $\mathbf{w}^{(n)} = [w_{1,n} \ w_{2,n} \ \cdots \ w_{L,n}]^T$ of size $(L \times 1)$ where $n=1, \dots, N$ that consists of the n -th weights of all L elements. Figure 3 depicts antenna patterns obtained by $\mathbf{w}^{(17)}$ and $\mathbf{w}^{(27)}$, *i.e.*, the large amplitude weights. It is clarified that the two weights vectors generate beams towards DOA of signals. These observations imply the fact that components of the weight vector \mathbf{W} can be replaced with 0 except the components included in $\mathbf{w}^{(17)}$ and $\mathbf{w}^{(27)}$. After performing such operation, we obtain the output SNR 11.9dB.

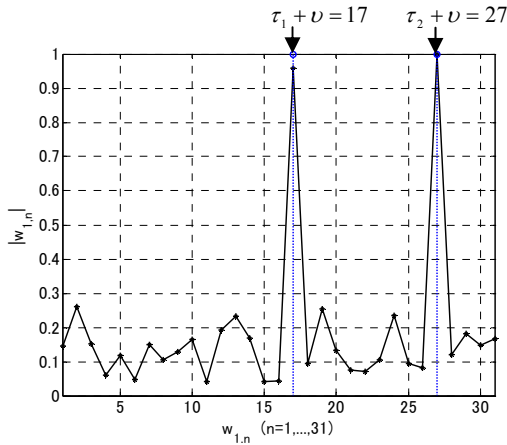


Figure 2 Absolute values of $\mathbf{w}_{1,n}$.

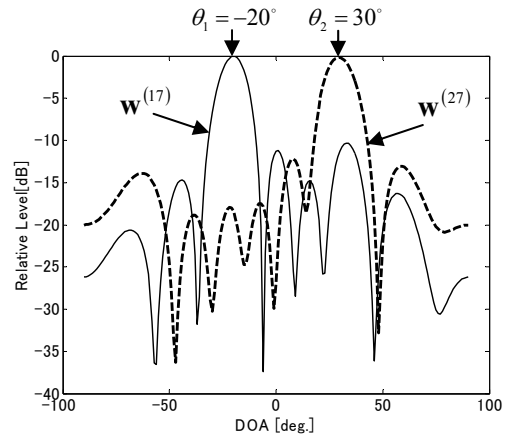


Figure 3 Antenna patterns of $\mathbf{w}^{(17)}$ and $\mathbf{w}^{(27)}$.

As Figure 2 implies, it is clearly observed that the weights corresponding to the bit timing $\mathbf{w}^{(17)}$ and $\mathbf{w}^{(27)}$ keep the large amplitudes while the others are suppressed. Since it means that the others do not contribute to the improvement of the output SNR, it should be possible to fix the other weights to 0 without performing the adaptive control. In addition, it is expected to reduce the convergence speed by fixing the weights that do not correspond to the bit timing during the convergence due to the fact that the convergence of the steepest descent method is a function of the number of weights^[3].

Through these insights, a convergence acceleration technique is proposed. The procedure is as:

Step 1. Calculate iteratively eq. (7) as increasing the index k .

Step 2. If k becomes larger than a threshold β :

- a. Detect N_f taps corresponding the weight with the largest till the N_f -th largest amplitude where N_f is the number of the RAKE fingers.
- b. Set the other weights as 0 and reduce the size of \mathbf{w}_ℓ in eq. (5) to $(1 \times N_f)$.

Step 3. Continue the iteration of eq. (7).

4 A Numerical Example and Statistical Evaluations

This section consists of two computer simulations. One is a numerical example as an event evaluation while the other is a statistical evaluation that is derived from 100 snapshots generated by using randomly-defined parameters.

As the event evaluation, Figure 4 compares the convergence of the output SNR between the blind 2D-RAKE with and without the proposed method. In this simulation, conditions are identical with those listed in Table 1 except the input SNR is set as -3dB/element/chip. It results in 9dB as the

output SNR if the 2D-RAKE is properly accomplished. In addition, β is set as 30. It is obvious that the proposed convergence acceleration method reduce the convergence time.

Next, as the statistical evaluation, DOAs and the phase of the two incoming signals are set randomly in each snapshot. Then, 100 snapshots are generated for each delay of the second ($m = 2$) incoming signal while the delay of the first ($m = 1$) one is fixed as 0. Figure 5 shows the average output SNR obtained by the 100 snapshots for each delay between the two cases, $\alpha = 1$ (31 taps) and $\alpha = 2$ (62 taps) where the proposed acceleration method is employed. It is seen that the both cases achieve around 9dB output SNR till the delay $31 T_c$ even though the case $\alpha = 2$ degrades around 3dB for the delay more than $31 T_c$. This is due to the ability of RAKE combining limited by the length of the taps. Here, it should be emphasized that the blind 2D-RAKE combines the multipath signals delayed more than the bit duration. At $31 T_c$, output SNR degradation is found since this point prevents the 2D-RAKE from separating the two signals.

Through these computer simulations, it is verified that the proposed acceleration technique reduce the convergence without any degradation of the performance of the blind 2D-RAKE.

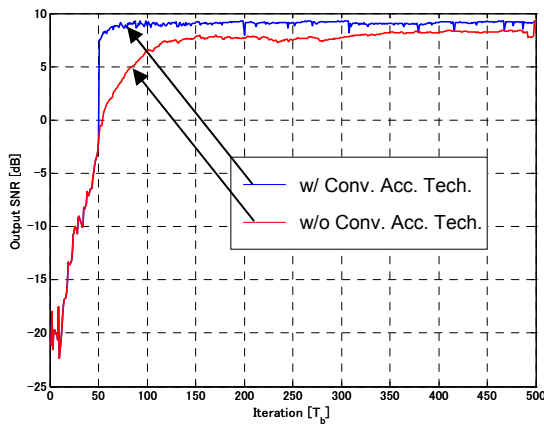


Figure 4 Comparison of the convergence of between the output SNR with and without the proposed method.

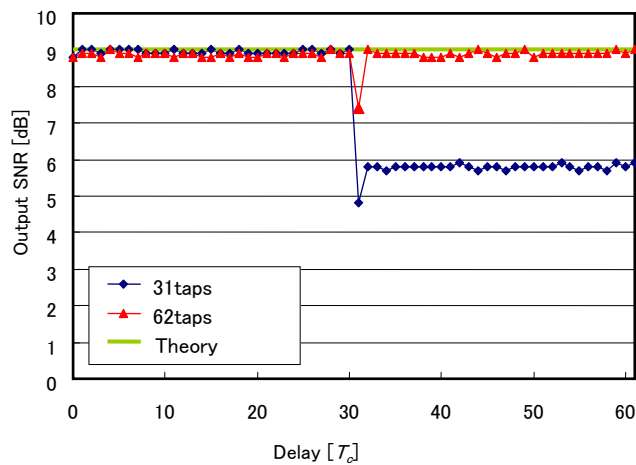


Figure 5 Comparison of the average output SNR using 31 and 62 taps with the proposed method.

5 Concluding Remarks

In this paper, a convergence acceleration technique is proposed for the blind 2D-RAKE receiver. Through computer simulations, it has been verified that the proposed scheme reduce the convergence without any degradation of performance. As a further consideration, the performance under more realistic fading environment will be examined.

References

- [1] J.G. Proakis, "Digital Communications," McGraw-hill Inc., 1995.
- [2] K. Takayama, Y. Kamiya, "A Consideration on Blind Spatio-Temporal RAKE receiver based on CMA criteria," Proceeding of the 2004 IEICE Society Conference, B-1-190, September 2004.
- [3] S. Haykin, "Adaptive Filter Theory," Prentice Hall, Inc., 2001.