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Research paper

WCDMA Systems Investigation with a Combination of Rake Receiver and Sub-Block Antenna Array Processing for Multiuser Detection

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Abstract

This paper presents a new amalgamation of the RAKE receiver with three-fingers, and the Sub-Block-Based Normalized Least Mean Square-Despread-Respread Multi-Target Array (NLMS-DRMTA) algorithm for multiuser detection in Wideband Code Division Multiple Access (WCDMA) systems. The new method uses together temporal diversity and the space diversity, for getting a significant enhancement in Bit Error Rate (BER) performance, As well as reducing unwanted signals and Indirect signals effects. The combination of the rake receiver and the Sub-Block-Based algorithm was compared versus the single antenna CDMA and sample-based NLMS-DRMTA algorithm. This method can equip users more than the number of antenna array elements. Consequently, it is an extra productive strategy for expanding channel limit. Thus, it opens the route to an answer for limiting the impacts of multipath effects and interference from other users, in this manner enhancing the quality of services. Simulation results show that the sub-block algorithm overcomes the others without a rake system in both environments (AWGN or/and multipath fading). But with the rake, this algorithm will suffer from degradation in its BER performance. Also, the sample base algorithm takes advantages performance in the presence of rake receiver.

Keywords: *WCDMA, Adaptive Antenna Array, RAKE Receiver, DRMTA Adaptive Algorithms, Sample-Based NLMS-DRMTA.*

1. Introduction

CDMA is a technique where a narrowband user signal multiplied by a pseudo code, and the most important characteristic of the codes is orthogonal to each other in the cell. This technique has many advantages. Consistent with that the users here can share the same frequency and the same time domain of the cell lead to maximizing the channel capacity, and for any single user the coded messages of the remaining users will appear as noise in the back of the received signal, as well as it provides the resistance to the jamming [1]. Ever since increasing the number of users will increase the noise inside the cell, then the cell can take an unlimited number of users under a condition that SNR stays correctable, this is considered a CDMA capacity limitation [2].
The WCDMA introduce preferable detection under Additive White Gaussian Noise (AWGN) channel using a simple correlator receiver [3]. Another effect of the channel is the multipath fading which a RAKE technique has usually been taken on as an effective means for decreasing this effect by applying temporal diversity [4]. However, RAKE is hopelessness to extract Multi-Access Interference (MAI) from AWGN channel. Therefore, the achievement is still not satisfactory [3]. The solution is to use Digital adaptive beamforming. The adaptive beamformer extracts the wanted signal by directing the main beam towards the Angle of Arrival (AOA) of the user and the nulls towards the directions of other active users. The researchers published in these years a new receiver to resolve both the co-channel interference and the multipath of the signal involved in the channel ([3], [4], [5], [6], [7], [8], and [9]). In this research, we are testing one of the best combinations of a RAKE receiver with an adaptive antenna array adopted by the Sub Block NLMS-DRMTA algorithm that proposed in [5], then compared its performance with Sample base NLMS-DRMTA algorithm that proposed in [10] and with the conventional CDMA. The performance has been tested regarding bit error rate in the presence of multipath environment, interference, and noise. In this combination, the size of users can override the size of antenna array beamformer without high decreasing to the performance [8].

2. System Model

The technologies that have been integrated to complete the system in its final form are CDMA, Rake receiver and smart antennas. Mathematical representation of each technique will be illustrated in this section.

2.1. CDMA Receiver

The DS-CDMA received signal is given by (1).

$$\mathbf{x}(t) = \sum_{m=1}^{M} \boldsymbol{x}_{\boldsymbol{m}}(t) s_m(t) + \mathbf{n}(t) \quad (1)$$

Where $\boldsymbol{x}_{\boldsymbol{m}}(t)$ the m-th user is received signal, the number of lively users at the same cell is M, and the AWGN noise is given by: $\mathbf{n}(t)$. Where $\boldsymbol{x_m}(t)$ can explicit as shown in (2) [3].

$$\boldsymbol{x_m}(t) = \sum_{k=-\infty}^{\infty} s_m(t) \,.\, [h_m(t-kT) * c_m(t-kT)] \quad (2)$$

Where $s_m(t)$ is the Binary phase shift keying (BPSK) signal of the m-th user, which has a unit amplitude as a sequence of pulses and time duration with period T. $h_m(t)$ and $c_m(t)$ are the channel impulse response and the m-th pseudorandom (PN) code, given by (3) respectively[3].

$$\boldsymbol{c_m}(t) = \sum_{n=0}^{SF-1} c_m(n) \,.\, \varphi(t-kT_c) \quad (3)$$

Where $\varphi(.)$ is the chip pulse shaping; SF is the chip rate divided by bit rate, and Tc=T/SF is the chip period. Each user is authorized by a different PN code used for spreading its data. The CDMA detector is a simplistic correlator between the received signal x(t) and the PN code $c_m(t)$ to isolate every user [4]. The receiver output is given by (4).

$$r_m(k) = \int_{kT}^{(k+1)T} x(t) c_m(t-kT)\, dt \quad (4)$$

The output f this receiver is adjusted beneath the condition that the PN codes are orthogonal concerning others under AWGN channel.

2.2. RAKE Receiver

The RAKE receiver is a well-known technique used to tackle the indirect signals issue [3]. It is worked by appointing a finger to each multipath signal and enhance the correlation job under the presumption the perfect phase delay of each multipath signal is computed. The output of the system is the summation of all signals from each finger. The output system can express as appeared in (5) [3], and depicted in Fig. 1.

$$r_m(k) = \sum_{l=1}^{L} \boldsymbol{\alpha}_{\boldsymbol{lm}}^*(n) \int_{kT}^{(k+1)T} x(t) c_m(t-kT)\, dt \quad (5)$$

The number of fingers is L, and the weighting factor of the l-th finger and m-th user is $\boldsymbol{\alpha}_{\boldsymbol{lm}}^*$.

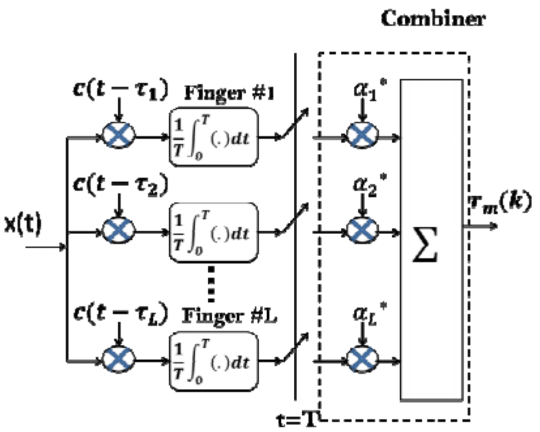

Fig. 1. Rake receiver model [3].

2.3. Adaptive Antenna Array Beam forming

Adaptive Antenna technology has been broadly utilized in 3G and 4G systems as a powerful means to surge the channel capacity of the cellular system and also improve the quality of service [5]. The operation of an adaptive antenna array is guided its beam-pattern toward the angle of arrival (AOA) of the wanted user and null other users to decrease the multi-access interference, see figure. 2.

In our case, there are M-active users event simultaneous in the N-elements of Uniform Linear Array (ULA) providing full situation. The AOA vector for each user clarified as $\boldsymbol{\theta} = [\boldsymbol{\theta_0}, \dots, \boldsymbol{\theta_{N-1}}]^{\boldsymbol{T}}$. The array factor can be expressed by the summation of the N-phases vector. The AOA vector and the array factor can be represented as (6) and (7) respectively [5]:

$$\overline{\boldsymbol{a}}(\theta) = \left[1 \; e^{j(kd\sin(\theta))} \dots e^{j(M-1)(kd\sin(\theta))}\right]^T \quad (6)$$

$$AF\,(\theta) = sum(\overline{a}(\vartheta)) = \sum_{n=1}^{N} e^{j(n-1)\varphi} \quad (7)$$

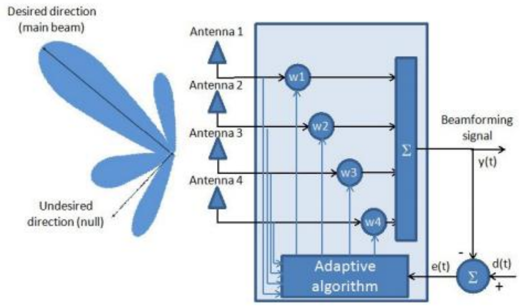

Fig. 2: Graph of the adaptive antenna array technique [11].

Where $\psi = kd\sin(\theta) + \beta$, $k = 2\pi/\lambda$, λ is the wavelength, d=λ/2 is the inter-element spacing and β is the initial phase [5].
Then, the input vector $x(t)$ of the ULA array can be demonstrated as (8) [3].

$$x(t) = a(\theta_1)\, s_1(t) + \sum_{i=2}^{i=M} a(\theta_i)\, s_i(t) + \sum_{i=1}^{i=M} \sum_{q=1}^{q=m} a(\theta_{iq})\, s_{iq}(t) + n(t) \quad (8)$$

The Eq. (8) appears the wanted user signal, the interference signals from the other (M-1) users, m-th multipath signals, furthermore, the last term is the AWGN noise respectively. Then, the output of the adaptive array beam forming is expressed as (9) [5].

$$\boldsymbol{y}_i(n) = \boldsymbol{\omega}_i^H(n) \boldsymbol{X}(n) \quad (9)$$

Where $\boldsymbol{\omega}_i$ is the M×1 weight coefficients of user i. The superscript H denotes the Hermitian of a k-by-n matrix.

3. Receiver System

The Sub-Block NLMS-DRMTA algorithm used in this research. The modern algorithm doesn't need for the training signal because it employs the despread-respread technique to produce the desired signal and then using a new kind of the NLMS algorithm to calculate the weight coefficients [5].

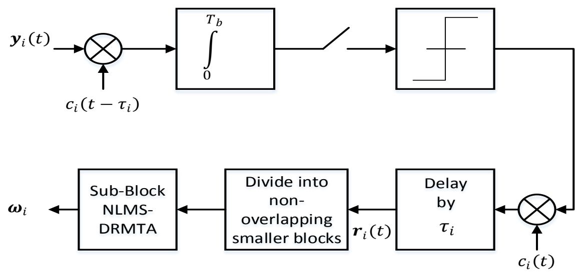

Fig. 3: Graph of the Sub-Block NLMS-DRMTA Algorithm [5].

The reference signal $r_i(n)$ is divided into little pieces as a blocks and apply new NLMS optimization for each of the littler blocks to produce the weight vector $\omega_i(n)$. Figure 3 shows the procedure of the algorithm for user i [5].
From Eq.(1), signal bit, X, has K-th samples of length is separated into a smaller blocks, every piece has size $p = K/P$ to create the matrix $\boldsymbol{G_j}$ where P is the number of blocks in each bit, and size of $\boldsymbol{G_j}$ is M×p as:

$$\mathbf{G_1} = [\mathbf{x}(p), \mathbf{x}(p-1), \dots, \mathbf{x}(1)\,] \tag{10}$$

The next block of p samples is the next block without any no meeting between neighboring blocks. Thus $\boldsymbol{G_2}$ is given as:

$$\mathbf{G_2} = [\mathbf{x}(2p), \mathbf{x}(2p-1), \dots, \mathbf{x}(p+1)\,] \tag{11}$$

$$\mathbf{G}_j = [\mathbf{x}(jp), \mathbf{x}(jp-1), \dots, \mathbf{x}(jp-p+1)\,] \tag{12}$$

Where j=1,2,…,P. The algorithm can be brief with the procedure presented in (13), (14), (15) and (16).

$$\mathbf{r}_{i,j} = [r_i(jp), r_i(jp-1), \dots, r_i(jp-p+1)\,] \tag{13}$$

$$\mathbf{y}_{i,j} = \boldsymbol{\omega}_{i,j-1}^H \mathbf{G}_j \tag{14}$$

$$\mathbf{e}_{i,j} = \mathbf{r}_{i,j} - \mathbf{y}_{i,j} \tag{15}$$

$$\mathbf{g}_{i,j} = \mathrm{Var}(\mathbf{G}_j) \tag{16}$$

Where $\boldsymbol{g}_{i,j}$ is the 1×M vector calculated by the variance operation to the each column of $\boldsymbol{G}_j$.

$$\mu_{i,j} = \alpha \frac{\sqrt{\mathbf{g}_{i,j}}}{\mathbf{g}_{i,j}\mathbf{g}_{i,j}^H} \tag{17}$$

$$\boldsymbol{\omega}_{\boldsymbol{i},\boldsymbol{j}} = \boldsymbol{\omega}_{\boldsymbol{i},\boldsymbol{j}-\mathbf{1}} + \mu_{i,j}\mathbf{G}_j\mathbf{e}_{i,j}^H \tag{18}$$

Where $\boldsymbol{\omega}_{i,j}$ and $\mu_{i,j}$ are the weight vector and step size for user i at iteration j respectively. In this simulations, α is 2 for P=1 and 0.5 for P=2 for optimum results [5].

4. Simulation Results

This section presents a comparison of the performance of receiver by utilizing each of SUB NLMS-DRMTA algorithm, sample based NLMS-DRMTA algorithm and Simple CDMA receiver with according to SNR and BER be presented. Next step is to demonstrate the efficiency of the new receiver with two other kinds of receivers that declared above. Before anything, illustration of experiment situation is highly recommended. Table 1 as shown below illustrates the experimental situation.

Table 1: Simulation Parameters Settings

Parameters	Table Column Head
Antenna element array	8
Number of users	16
Channel	a- AWGN Channel b- AWGN Channel + multi-path fading
Modulation technique	Binary phase shift keying(BPSK)
Spreading code	Orthogonal Walsh code of length 16
Path attenuation	1, 0.2 and 0.5
Number of RAKE finger	1, 2 and 3
Paths delay	0Tc, 0.5Tc, and 1.5Tc
Users which studied in this experiment	User 3 with AOA = 26° near middle User 7 with AOA = 73° near end fire
Comparison dependency	BER VS SNR

The figure 4 Demonstrates the performance analysis of the three previously declared receivers without RAKE in AWGN environment for BER and SNR for 8 element uniform linear antenna with 16 users for the desired user with AOA=26° (near the middle). It can be simply realized that Sub-Block NLMS-DRMTA algorithm has better performance in BER in same SNR and BER go zero faster than other algorithms and this show up SNR=5 for Both P=1 and P=2 while SNR for sample bases algorithm go zero at SNR=9 and CDMA with a simple correlator receiver does not go to the zero in our experiment (SNR is in range from -4 to13).

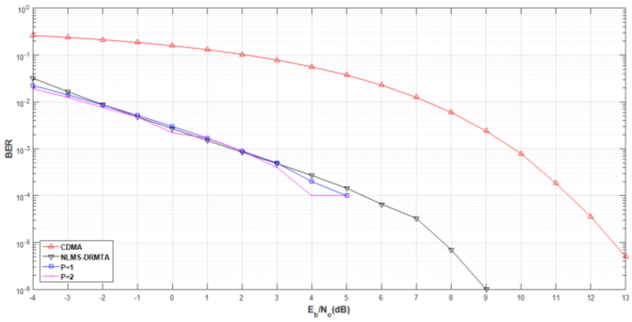

Fig.4: BER performance for AOA=26° in an AWGN without RAKE.

In Figure 5, The execution results is showing the impact of adding multipath fading with the AWGN channel for the desired user with AOA=26 °. Each multipath components of the desired user's signal delayed by 0, τ1, and τ2. The attenuation coefficients channel of these paths are closed to be 1, 0.5, and 0.2. The CDMA receiver has been altogether corrupted because of its failure to suppress multipath impacts even at high SNRs where it has flat curve around BER=0.2 at total range of SNR. Hence CDMA receiver has very poor and not acceptable performance in fading channel. In other hand, we have good performance for Sub-Block NLMS-DRMTA algorithm in comparison with sample-based algorithm and CDMA receiver which the BER go faster to zero at the same SNR. Also, when P=2 the performance is better than P=1.

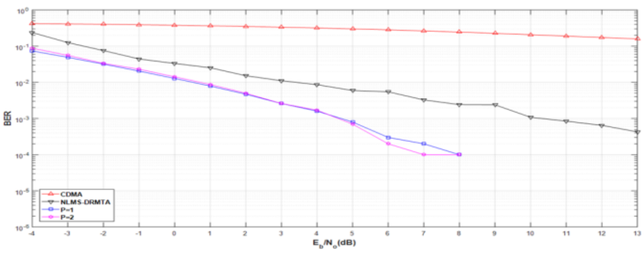

Fig.5: BER performance in a 3-path for AOA=26° without RAKE.

The performance analysis of 2-finger RAKE receivers are depicted in Fig.(6) for desired user with AOA=26°. Fig.(6) shows the effect of adding a multipath component of 0.2 weight, which results bad performance for the Sub Block NLMS-DRMTA algorithm. But it can be seen easily that the performers of sample based algorithm is better than others. The BER of sample-based algorithm go quicker to zero in comparison with Sub Block NLMS-DRMTA algorithm and CDMA receiver and go zero at SNR=9 and ditto has lower BER at same SNR compare with all 3 other curves. Hence, in this case, sample-based algorithm has better performance compare with SUB-Block algorithm and CDMA receiver.

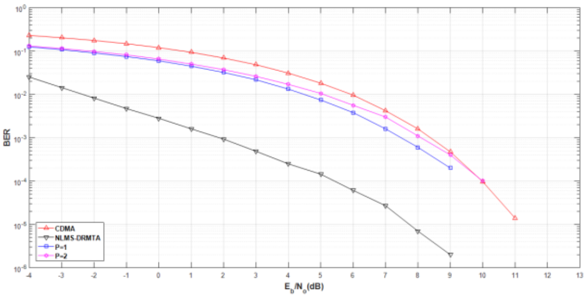

Fig.6: BER performance in a 2-path for AOA =26º with 2-finger RAKE (a0=1, a1=0.2).

When the weight of Fig.(6) is increasing to 0.5 would further decrease the BER of the sample based algorithm and CDMA receiver, while the Sub-Block NLMS-DRMTA algorithm still bad performance, as depicted in Fig.(7). The performance of sample-based algorithm increase which BER go to zero faster at SNR =8 and in same SNR has lowest BER compare with other two algorithms. Hence in this case sample –based has better performance compare with other two algorithms.

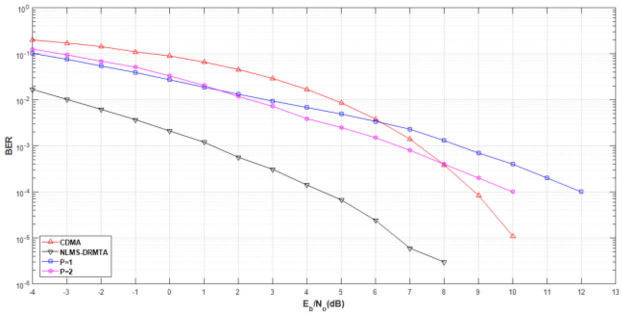

Fig.7: BER performance in a 2-path for AOA =26º with 2-finger RAKE (a0=1, a2=0.5).

Figure 8 shows BER performance analysis in AWGN and fading channel with 3 paths with weighted 0.2 and 0.5 of our new receiver, 3-finger RAKE with adaptive array, relative to 3-finger RAKE with CDMA and 3-finger RAKE with NLMS-DRTMA beam formers for the desired user with AOA=26º.it can be seen that easily sample based algorithm has the better performance compare with others.

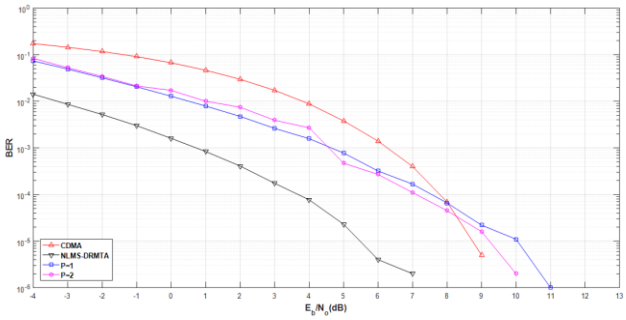

Fig.8: BER performance in a 3-path for AOA =26º with 3-finger RAKE (a0=1, a1=0.2, a2=0.5).

The new receiver is also verified by simulating very hostile conditions, whereby the AOA is close to the end-fire of the antenna array. The figures 9 to 13 are showing the performance analysis for BER versus SNR at AOA of the wanted user = 73° (near end-fire). At 73°, the performance antenna array up to the lower limits and the beam pattern would become broader. Accordingly, the nearness of different users at adjacent AOAs and multipath interferences would bring about the signal of the wanted user to radically degrade and unfavorably influence the BER performance. In overall, the sample based algorithm has the better performance contrast and sub-block base algorithm and CDMA receiver, and the sub-block with P=1 is always better than sub-block with P=2.

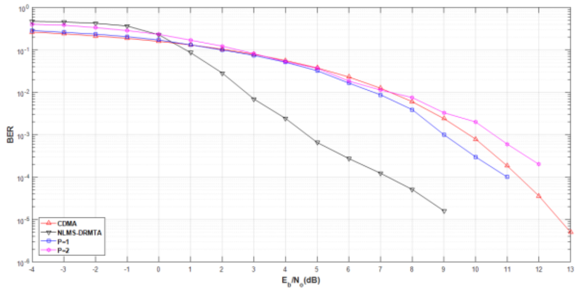

Fig.9: BER performance for AOA = 73º without RAKE).

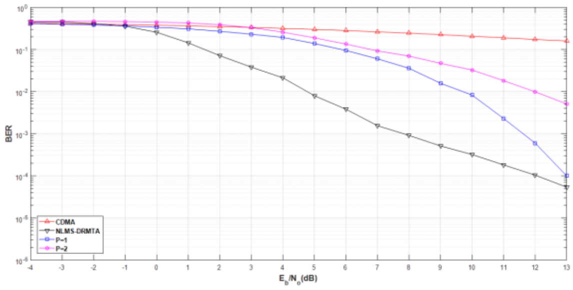

Fig.10: BER performance for AOA=73º without RAKE.

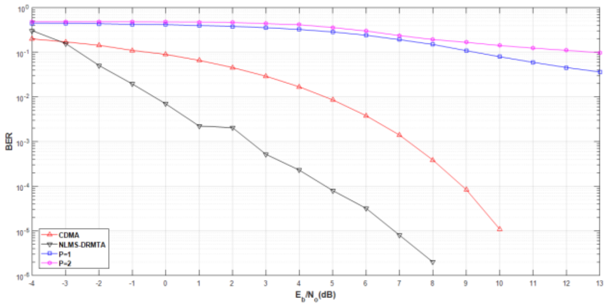

Fig.11: BER performance in a 2-path for AOA =73ºwith 2-finger RAKE (a0=1, a2=0.5).

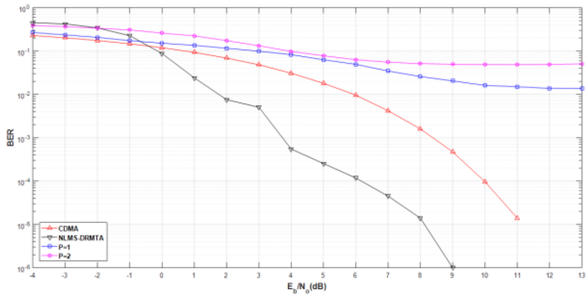

Fig.12: BER performance in a 2-path for AOA =73º with 2-finger RAKE (a0=1, a1=0.2).

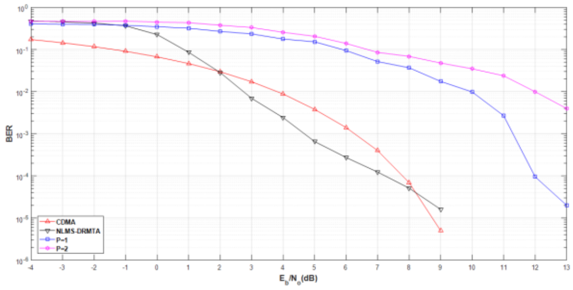

Fig.13. BER performance in a 3-path for AOA =73º with 3-finger RAKE (a0=1, a1=0.2, a2=0.5).

5. Conclusion

In this work, we found that the Sub-Block Based algorithm has the best performance and the faster performance in AWGN channel with and without fading compare with Sample Base algorithm. But by adding rake receiver, the new receiver gets weaker performance compare with the sample-based algorithm. Where sample-based algorithm gets better performance in all cases with RAKE receiver. Hence the combination of Sub-Block-adaptive beam forming with a RAKE receiver is not appropriate and sample-based adaptive beam forming is better with a RAKE receiver. In general, when the Block or Sub-Block DRMTA algorithms, if the data bit is not predicted properly at the start of the algorithm with rake receiver, the resulting weight vector will have a phase shift of π, but this remained the beam pattern still have a higher gain in the DOA of the desired signal and the interference from other directions will be rejected.

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