TIME-SPACE SIGNAL PROCCESSING FOR CDMA USING RECEIVING CONFIGURATION WITH RAKE RECEIVERS

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Abstract: We are concerned with time space signal processing in CDMA system, which uses specific receiving configuration with RAKE receivers. This configuration is improving the system performances while decreasing the system capacity. Antenna array could provide capacity improvement while keeping the good performances from time processing. Actually this is conventional time space signal processing performed on CDMA system using Gold codes as spreading sequences. The basic principal is presented, and any change in system characteristics could be appropriately implemented.

I INTRODUCTION

Let us consider CDMA (Code Division Multiple Access)[4] system consisted of Q user signals with multipath propagation. We suppose that the valid paths could be discretely selected and that their number is L. The base station is equipped with antenna array with m elements-isotropic radiators. The user is transmitting the signal $x(t)$ and if we neglect path loss and amplitude variations (or if we assume that are compensated with other means in the system), the signal vector at the antenna array output in kth symbol interval for one user will be:

$$\mathbf{x}(t)=\sum_{l=1}^{L}\mathbf{a}(\theta_l)\cdot x_l(t-\tau_l)+\mathbf{n}(t),\ kt<t<(k+1)T \qquad (1)$$

where τ_l is the time delay of the lth path, $\mathbf{a}(\theta_l)$ is Antenna Response Vector (ARV)[3], $\mathbf{n}(t)$ is the m element vector of Gaussian noice, and T is the symbol interval. In the case of CDMA system using spreading codes $c(t)$ with P chips, the signal vector is:

$$\mathbf{x}(t)=\sum_{l=1}^{L}\mathbf{a}(\theta_l)\cdot s_k\cdot c(t-\tau_l)+\mathbf{n}(t) \qquad (2)$$

where s_k is the bit value in kth symbol interval (for BPSK –1 or 1). If we have Q active users than the signal vector at the output of the antenna array will be:

$$\mathbf{x}(t)=\sum_{i=1}^{Q}\sum_{l=1}^{L_i}\mathbf{a}(\theta_{il})\cdot s_{ik}\cdot c_i(t-\tau_{il})+\mathbf{n}(t) \qquad (3)$$

where τ_{il} is time delay of the lth path of the ith user.

II TIME-SPACE PROCESSING

In order to exploit both time and space signal processing [3] we are going to do joint Time Space Processing-TSP as shown in Fig.1. The principal explanation of space processing could be found in [6] and of time processing in [8]. The KFR is presenting the configuration of RAKE [3] receivers, one for each user. We should say that Fig.1 is presenting the functional system scheme, both parts I and II are in the same physical space. There are $L_j m$ phase shifters, adjusted for all valid path of jth user. With each phase shifter there is delay line adjusted for corresponding path (the concept of RAKE receiver). After this configuration we are getting the signal:

$$y_j(t)=\sum_{v=1}^{L_j}\sum_{i=1}^{Q}\sum_{l=1}^{L_i}\mathbf{a}(\theta_{jv})^{\mathrm{H}}\cdot\mathbf{a}(\theta_{il})\cdot s_{ik}\cdot c_i(t-\tau_{il}+\tau_{jv})+n'(t) \qquad (4)$$

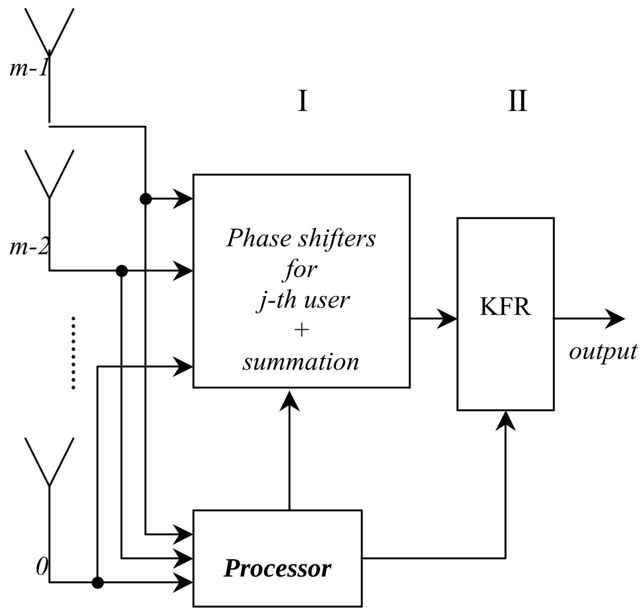

Fig. 1 Functional scheme of the configuration with RAKE receivers

After passing the signal through Matched Filter[1,2] we have:

$$z_j=\sum_{v=1}^{L_j}\sum_{i=1}^{Q}\sum_{l=1}^{L_i}\mathbf{a}(\theta_{jv})^{\mathrm{H}}\cdot\mathbf{a}(\theta_{il})\cdot s_{ik}\cdot c_i(t-\tau_{il}+\tau_{jv})*c_j(t)+n'' \qquad (5)$$

where the operation " ∗ " is defined as:

$$c_i(t+t_i)*c_j(t+t_j)=\int_{\Lambda}\mathrm{c}_i(t+t_i)\cdot c_j(t+t_j)\cdot \mathrm{d}t,$$

$$\Lambda\equiv\{t,t\in(c_i(t+t_i)\neq 0\wedge c_j(t+t_j)\neq 0)\}$$

This expression could be presented as:

$$z_j = L_j \cdot m \cdot P \cdot s_{jk} + \sum_{v \neq l}\sum_{l} \mathbf{a}(\theta_{jv})^{\mathrm{H}} \cdot \mathbf{a}(\theta_{jl}) \cdot s_{jk} \cdot c_j(t - \tau_{jl} + \tau_{jv}) * c_j(t) +$$

$$\sum_{v}\sum_{i \neq j}\sum_{l} \mathbf{a}(\theta_{jv})^{\mathrm{H}} \cdot \mathbf{a}(\theta_{il}) \cdot s_{ik} \cdot c_i(t - \tau_{il} + \tau_{jv}) * c_j(t) + n'' \qquad (6)$$

If we use the autocorrelation Φ_{jj} and crosscorrelation function Φ_{ij} of the spreading CDMA codes we can write:

$$z_j = L_j \cdot m \cdot P \cdot s_{jk} + \sum_{v \neq l}\sum_{l} \mathbf{a}(\theta_{jv})^{\mathrm{H}} \cdot \mathbf{a}(\theta_{jl}) \cdot s_{jk} \cdot \Phi_{jj}(\tau_{jv} - \tau_{jl}) +$$

$$\sum_{v}\sum_{i \neq j}\sum_{l} \mathbf{a}(\theta_{jv})^{\mathrm{H}} \cdot \mathbf{a}(\theta_{il}) \cdot s_{ik} \cdot \Phi_{ij}(\tau_{jv} - \tau_{il}) + n'' \qquad (7)$$

The first part is presenting the useful signal. The second part is presenting the result of not adjusted paths of the user of interest. This part should be suppressed by time processing, which demands low values of autocorrelation function of CDMA codes. The reason for this is the fact that the value of the expression $\mathbf{a}(.)^{\mathrm{H}}\mathbf{a}(.)$ is relatively high (for small angle spread values). The third part is presenting the interference and most of it will be suppressed by space processing.

We are going to use KFR for all users that have important influence on the interference level. Actually those are the users whose signal directions are in the main lobe area. This system is presented in Fig.1.

The function of the processor is to give instructions for that which users should be taken into account, which will provide corresponding adjustment of the phase shifters and delay lines [5].

The analyze so far, is performed for single user detection. The whole procedure could be performed for any other user and also for multi-user detection even for all users. This is a result of the fact that knowing the channels of all users (KFR) is providing signal detection for any user.

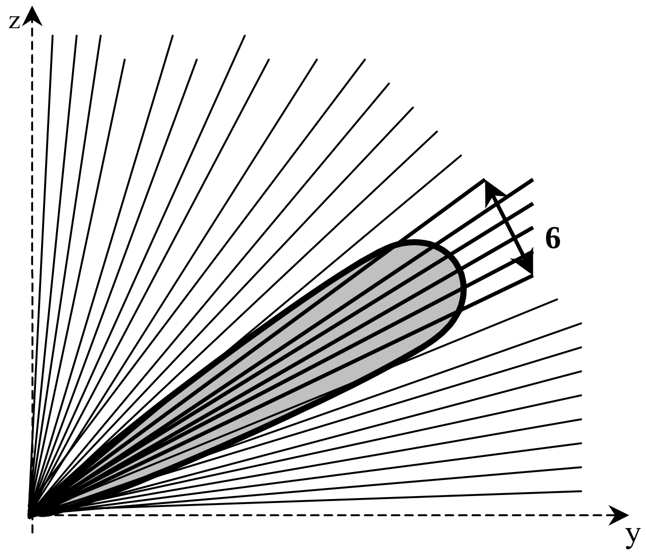

Fig. 2 Example of system with Q=60, using antenna array

The presentation of TSP could be finished by simple example. Let us have a system with 60 active users, uniformly distributed in the space θ∈(0°,180°). For CDMA in this case we need spreading codes with length of 63 chips (Gold codes). The number of valid paths for each user is arbitrary, namely the bigger number of valid resolvable paths provide better performances. With time processing we are going to improve the *BER* performances but in the same time we are going to reduce the system capacity to 10% of the total capacity [8]. In our example we are going to be able to serve to about 6 users. If we use antenna array for space processing in order to increase the system capacity, the width of the main lobe should be at most 20°. This example is presented in Fig.2. This illustration is presenting an idealized radiation pattern (no secondary lobes). The lines are presenting the signal directions of the 60 users. It is clear that 6 users are within the main lobe. These users further should be time processed.

In any case this example demands special antenna geometry, which will provide satisfactory directivity and low level of secondary lobes. But also this example is addressed to total usage of the maximal possible capacity (almost 63), for smaller number of users there are less rigorous demands. In the next chapter the computer simulations will show that because of the array gain, there can be more than 10% of the users within the main lobe.

III COMPUTER SIMULATIONS

Computer simulations are performed for antenna array with isotropic radiators, and the distance between two neighboring elements is chosen (expressed in wavelengths) in order to achieve desired directivity. The examination is performed for m=2 and m=4, and for Gold codes length, the value of 31 is selected. Also uniform user distribution is assumed.

Fig.3 is presenting *BER* (Bit Error Rate) performances for 4 valid paths, for maximal path delay of $3T_c$ (T_c is the time chip interval), d=0.5, Q=10 users and m=2. This values are corresponding to the case when within the main lobe there will be 5 users, which is more than 10% of total capacity, but we still have good performances. This is thanks to antenna array usage. Although with space processing we are selecting 5 users, the antenna doesn't receive all signals within the main lobe with same gain. The highest gain is for the user whose signal direction is in the middle of the main lobe, the other will be suppressed according the beam shape.

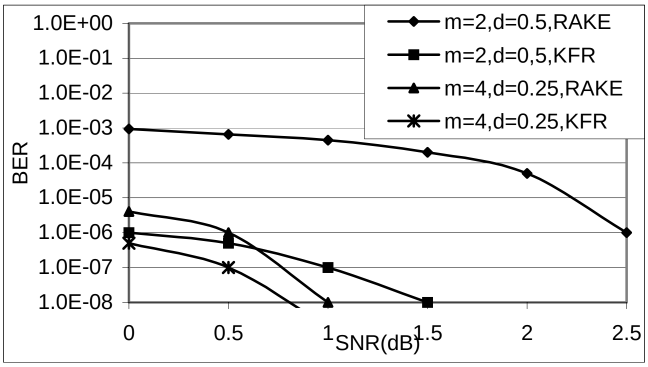

Fig. 3 BER performances for P=31,Q=10, L=4 and $\tau_{max}=3T_c$

The same figure is presenting the performances for array with L=4, $\tau_{max}=3T_c$, m=4, d=0.25 and Q=10. The improvements are obvious. This is thanks to decreased value of angle of directivity (larger number of elements).

Fig. 4 is presenting *BER* performances for L=4, $\tau_{max}=3T_c$, m=2, d=1.0 and Q=25. In this case although we assume no secondary lobes we get bad performances. The reason for this is the high load of the system (about 8 users within the main lobe) and low array gain. In the same figure the same example is presented but for array with m=4. The improvements are obvious.

From everything what we have said by now, the justification of KFR plus antenna array usage is obvious but only with total system planning: the number of users, the length of CDMA codes, number of antenna elements, and the choice of their distribution in the array.

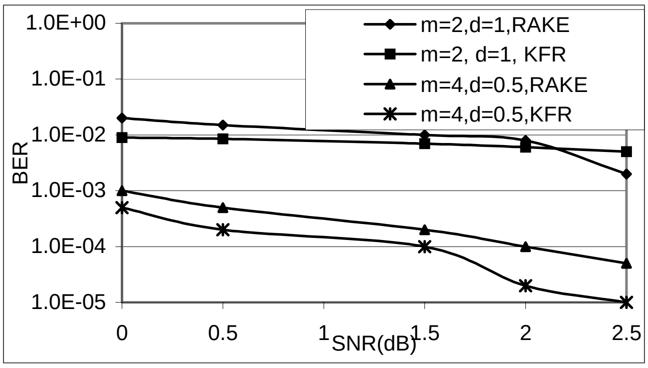

Fig. 4 BER performances for P=31,Q=25, L=4 and $\tau_{max}=3T_c$

IV CONLUSION

We were concerned with time space signal processing in CDMA system, which uses specific receiving configuration with RAKE receivers that was noted as KFR. With time processing we are going to improve the *BER* performances but in the same time we are going to reduce the system capacity to 10% of the total capacity, as explained in [8]. We used antenna array for space processing and we regained the lost system capacity.

Computer simulations were performed for antenna array with isotropic radiators, and the distance between two neighboring elements was appropriately chosen (expressed in wavelengths) in order to achieve desired directivity. The examination was performed for m=2 and m=4, and for Gold codes length, the value of 31 was selected. Also uniform user distribution was assumed. Complicated scenario, multipath propagation was examined, and the good performances was obvious. The gain from time and both space processing was jointly and successfully exploited.

We have examined an array of isotropic antenna elements, similar analyzes could be performed for real antenna elements, for example dipoles [7], and the conclusions will be the same, but taking into account the influence of the real antenna array pattern on the total system performances.

From obtained results, the justification of KFR plus antenna array usage is obvious but only with total system planning: the number of users, the length of CDMA codes, number of antenna elements, and the choice of their distribution in the array.

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