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Research Paper

CORDIC based QRD-RLS Adaptive Equalizer for CDMA Systems

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Abstract

The conventional RAKE receiver utilized in CDMA systems often falls short when dealing with propagation channels characterized by numerous paths and deep fading, leading to significant inter-user and inter-symbol interferences. This paper introduces an innovative adaptive equalizer based on the QRD-RLS algorithm, aiming to replace the traditional RAKE receiver. To address the computational complexity associated with RLS, the renowned CORDIC algorithm is leveraged, playing a pivotal role in the hardware implementation of this novel approach. Extensive simulations of the proposed RLS structure are conducted under various channel parameters, and its performance is compared to that of the conventional RAKE structure.

Key Words QRD-RLS, CORDIC, CDMA, Adaptive Equalizer

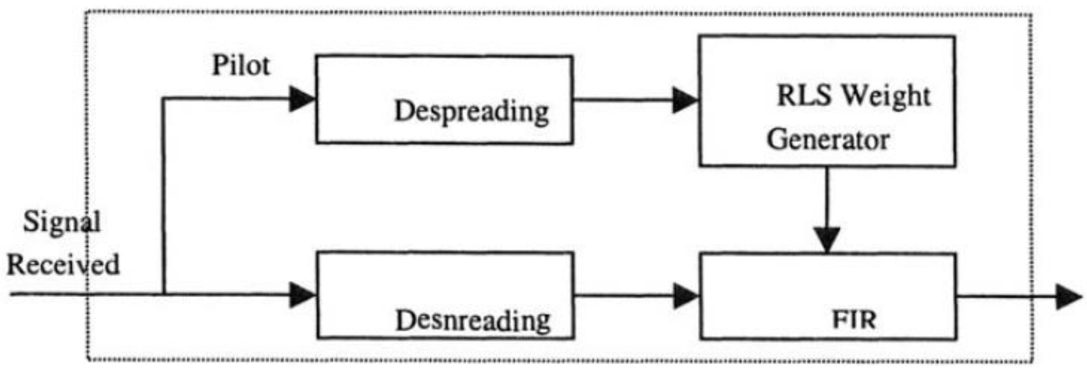
Introduction

Two significant challenges in wireless communication systems utilizing code division multiple access (CDMA) technology are time-varying multipath propagation and multiuser interference, both of which impact system capacity and performance. Commonly proposed strategies to mitigate these challenges include transmitter power control, diversity techniques, and error control coding. An alternative approach to address the distortions introduced by channel characteristics and multiuser interference involves replacing the traditional RAKE receiver with a more efficient equalizer employing adaptive algorithms such as Least-Mean-Square (LMS) and Recursive Least-Squares (RLS).

In the context of practical mobile radio systems characterized by time-varying Rayleigh fading channels, limitations in the number of RAKE fingers pose challenges in achieving satisfactory system performance as the number of channel paths increases and channel coefficients fluctuate rapidly. Moreover, escalating system complexity accompanies the addition of more RAKE fingers, necessitating the incorporation of a channel estimation module at the receiver side. Time Domain Equalizers based on LMS or RLS offer a potential solution to address issues related to multipath interference and errors stemming from channel estimation.

The RLS algorithm incorporates all the information dating back to initialization and updates the estimation of the tap-weight vector with the arrival of new data, making it preferable to the LMS algorithm due to its superior convergence properties. In RLS filtering, the orthogonal triangularization of the input matrix through QR-decomposition (QRD) plays a vital role. This triangularization process can be achieved through a series of Givens rotations, commonly used for QR updating on a sample-by-sample basis. Figure 1 depicts the block diagram of the proposed RLS-based adaptive equalizer structure for a CDMA receiver.

Figure 1: Structure of RLS Adaptive Equalizer in a CDMA system



With the rapid advancement of VLSI technology, systolic arrays have become practically viable for implementing QRD-RLS in hardware. The CORDIC (Coordinate Rotation Digital Computer) algorithm has been introduced as an alternative to conventional Givens rotations for performing two-dimensional vector rotations. This algorithm revolves around phase shifting via a sequence of "micro-rotations" using a fixed set of elementary rotation angles. By appropriately selecting these angles, all computations can be efficiently implemented in VLSI using a sequence of shift and add/subtract operations. Typically, a pre-established look-up table containing the elementary rotation angles is utilized for phase shifting, replacing trigonometric functions used in Givens rotations, which are impractical for hardware realization.

This paper delves into the design and development of a CORDIC-based QRD-RLS channel equalizer in a CDMA system and compares its performance with conventional RAKE structures.

The paper is structured as follows: Section 2 provides a brief overview of the mathematical principles of the QRD-RLS algorithm and discusses its limitations stemming from high computational complexity. Section 3 elaborates on the CORDIC algorithm and its hardware implementation. Additionally, it discusses how the CORDIC algorithm can address the computational challenges posed by the QRD-RLS approach. Section 4 focuses on simulation studies to evaluate the performance of the proposed approach.

QRD-RLS Algorithm

The RLS algorithm can be conceptually broken down into two key processes:

1. Calculation of Output: Initially, we compute the output of a transversal filter using a set of tap inputs. Subsequently, we compare this output with the desired response to estimate the error.
2. Error Minimization: Next, we devise a method to minimize this error by adjusting the tap weights of the transversal filter. This adjustment aims to approach the desired response more closely at the output.

Let d(n) d(n) represent the desired response vector at time n, u(n) denote the input signal vector at time n, and w(n) denote the tap weight vector we seek. The objective is to minimize the cost function:

$$E = \sum_{i=0}^{n} \lambda^{n-i} \left| d(i) - W^H(i)U(i) \right|^2 \quad (1)$$

Where λ represents the forgetting factor used to diminish the influence of past signals.
Equation (1) can be reformulated into a matrix format as follows:

$$\varepsilon = \| e(n) \|^2 = \| \Delta(n) - \Delta(n)A(n)W(n) \|^2 \quad (2)$$

where the symbol $\|\cdot\|^2$ stands for the squared Euclidean norm and:

$$\Delta = diag(\lambda^{n-1}, \lambda^{n-2}, \cdots, 1) \quad (3)$$

$$d^H(n) = [d(1), d(2), \cdots, d(n)] \quad (4)$$

$$A^H(n) = [u(1), u(2), \cdots, u(n)] \quad (5)$$

Concerning Equation (2), as multiplication by a unitary matrix doesn't alter the norm of a matrix, we utilize QRD to convert the weighted input signal matrix A(n) into an upper triangular matrix R(n). Simultaneously, the first part to the right of Equation (2) is transformed into two auxiliary matrices denoted as P(n) and V(n):

$$Q(n)e(n) = \begin{bmatrix} P(n) \\ V(n) \end{bmatrix} - \begin{bmatrix} R(n)W(n) \\ 0 \end{bmatrix} \quad (6)$$

where Q(n) is a unitary matrix.

It's straightforward to observe from Equation (6) that the cost function $\| V(n) \|^2$ approaches its minimum value when the following equation is satisfied.

$$\mathrm{R}(n)\ \mathrm{W}(n) = \mathrm{P}(n) \quad (7)$$

The process can be recursively advanced through a sequence of complex Givens rotations, resulting in the creation of the unitary update transformation matrix $Q(n)$:

$$Q(n) = J_M(n) \cdots J_2(n) J_1(n) \quad (8)$$

Here, J(n) represents the individual Givens rotation transformation matrix employed to eliminate the corresponding element in the signal vector entering the system at time n. Utilizing all these transformation matrices ensures that the non-zero vector a at the bottom is transformed into a zero vector.

$$\mathrm{J_M(n)} \cdots \mathrm{J_2(n) J_1(n)} \begin{bmatrix} \mathrm{R} \\ 0 \\ \vec{\mathrm{a}} \end{bmatrix} = \begin{bmatrix} \mathrm{R} \\ 0 \\ 0^{\mathrm{T}} \end{bmatrix} \quad (9)$$

$\mathrm{J_K(n)}$ is given as:

$$\mathbf{J}_k(n) = \begin{array}{c c} \begin{bmatrix} 1 & & & & & & \\ & 1 & & & O & & \\ & & \ddots & & & & \\ & & \cos\theta & 0 & \cdots & 0 & \sin^*\theta \\ & & 0 & 1 & \cdots & 0 & 0 \\ & O & \vdots & \vdots & \ddots & \vdots & \vdots \\ & & 0 & 0 & \cdots & 1 & 0 \\ & & -\sin\theta & 0 & \cdots & 0 & \cos\theta \end{bmatrix} & \begin{array}{c} 1 \\ \\ \\ k \\ \\ \\ \\ n \end{array} \\ \begin{array}{ccccccc} \quad & \quad & \quad\quad k & & & & \quad\quad n \end{array} & \end{array} \quad (10)$$

From Equations (7)-(9), as the data stream enters the equalizer row by row, it is effectively nullified to zero, simultaneously updating the matrices R(n) and P(n) accordingly. Consequently, acquiring the desired weight value via Equation (7) becomes straightforward.

CORDIC ALGORITHM AND ITS IMPLEMENTATION

3.1 CORDIC Algorithm

Considering Equation, trigonometric functions are employed here for orthogonal rotations. However, such functions are impractical for hardware implementation, especially concerning fixed-point values. To address this, the CORDIC algorithm is introduced, utilizing a look-up table to execute rotations through a series of sub-rotations.

The CORDIC algorithm offers two modes: the "vectoring" mode, used to determine the phase and magnitude of the input vector, and the "rotation" mode, which performs the actual rotation of the input vector. To execute Givens rotations, the "vectoring" mode is initially applied to determine the angle of rotation. Subsequently, the "rotation" mode is employed to rotate the vector through a series of sub-rotations for a specified number of iterations.

Consider a two-dimensional vector v, represented by $v = x + jy$ in the complex plane. If the vector is rotated by an angle θ, the new vector is expressed as $\tilde{v} = ve^{j\theta}$. The angle can be expanded into a set of elementary angles θ_i , with pseudo-digits $q_i \in (-1,+1)$ and an angle expansion error Z_{n-1}, such that

$$\theta = \sum_{i=-1}^{n-1} q_i . \theta_i + Z_{n-1} \quad (11)$$

here the sub-rotation angles θ_i take on the following values

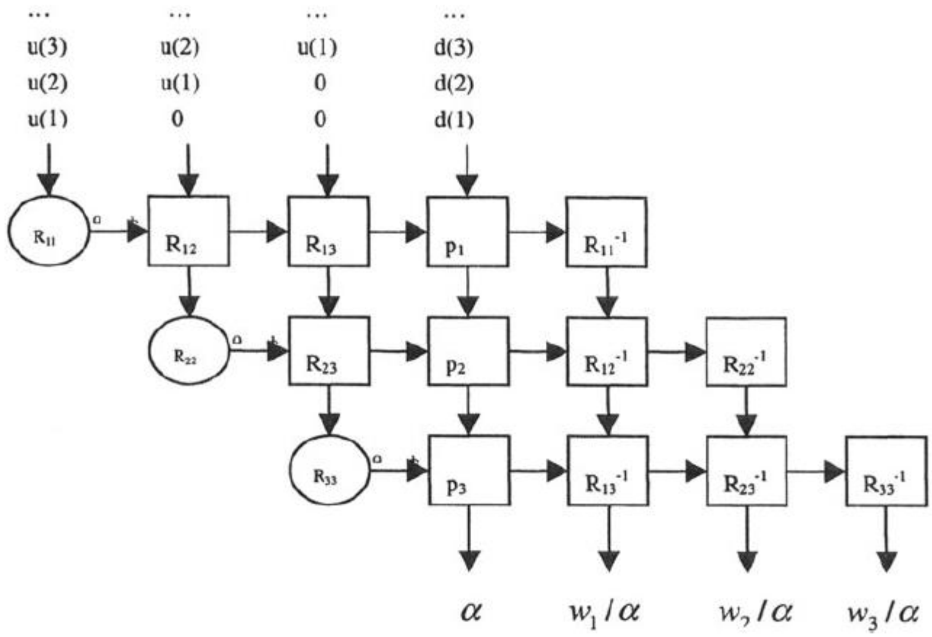
$$\theta_i = \begin{cases} \pi/2 & (i = -1) \\ \arctan(2^{-i}) & (i = 0,1,\cdots,n-1) \end{cases} \quad (12)$$

The pseudo-digits q_i are utilized to determine the direction of rotation based on the current value of z_i. In the vectoring mode, z_i is initialized to zero, and q_i is determined by the position of the current vector v during the updating process. Once the original vector has been rotated to align with the abscissa, the phase can be obtained from the value of z_i. Similarly, in the rotation mode, z_i is initialized with the desired rotation angle, and q_i is determined by the sign of the current z_i during the updating process. Upon completion of the loop, the vector v has been rotated as z_i approaches zero.

Systolic array

Another captivating aspect of CORDIC is that the determination of the rotation angle consumes the same number of clock cycles as the actual rotation. This characteristic facilitates the implementation of a systolic array for QRD-RLS filtering. In this context, the CORDIC algorithm is utilized to fulfill the function of every small cell in the systolic array, as illustrated in Figure 2. The cells in the figure are classified into two types based on their shapes: the roundshaped cell operates in "vectoring mode," while the square-shaped one operates in "rotation mode."

Figure 2: Structure of systolic array



Simulation results

The proposed system undergoes extensive simulation across various channel parameters, with its performance benchmarked against that of the conventional RAKE receiver. The CDMA-based transceiver structure employed in the simulation adheres to 3GPP standards, utilizing orthogonal variable spreading (OVSF) for channelization codes and a segment of Gold sequence for scrambling codes. A pulse shaping filter is integrated into the system to refine the chip signal and eliminate higher frequency components.

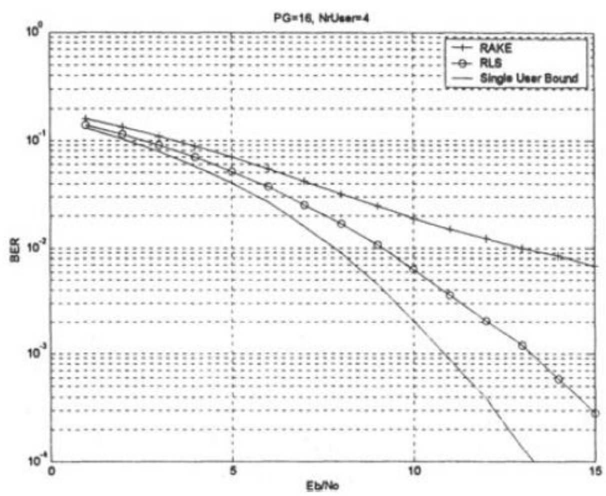
To enhance performance, two receiver-side antennas are deployed, employing a two-branch structure to reduce the taps required for the RLS equalizer. The downlink simulation system utilizes a Rayleigh fading channel model with 10 paths (denoted by L) and a maximum delay spread of 20 chips. The Doppler frequency (denoted by Fd) is relatively low in the simulation, indicating slow variations in the time-varying channel.

The system is characterized by a processing gain set to 16, and the number of users is set to a quarter or half of the system load. The system supports a total bandwidth of 5MHz, a chip rate of 3.84Mcps, and a data rate of 144kbps. It's important to note that the simulation assumes perfect synchronization and does not consider power control measures.

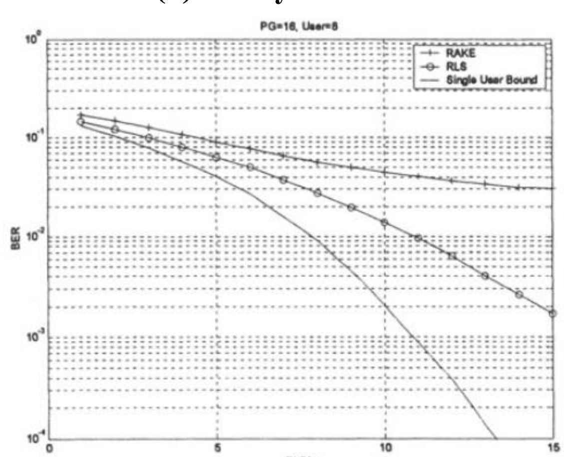
Figure 3 displays the simulation results of the proposed system. In each figure, the solid curve represents the bit error rate (BER) against signal-to-noise ratio (SNR) per bit across the Rayleigh fading channel when the number of users is set to single (single-user bound) [6], providing a reference for comparison. It's evident that the RLS equalizer significantly outperforms the conventional RAKE receiver by nearly 4 dB at a BER level of 10^{-2} in the case of a quarter system load. Additionally, as the number of users increases, the system performance deteriorates. However, the multi-user interference (MUI) resulting from the increase in the number of users doesn't impact the equalizer as severely as it does for the RAKE receiver. In both cases, a notable error floor can be observed for the RAKE receiver, whereas the performance of the RLS equalizer improves with increasing E_b/N_0.

Figure 3: Performance of the proposed method in a CDMA system

(a) quarter system load



(b) half system load



Conclusion

This study has introduced a novel approach to signal reception in CDMA systems by replacing the RAKE receiver with an adaptive equalizer based on the QRD-RLS algorithm. This choice is motivated by the QRD-RLS algorithm's excellent convergence properties and robustness against multipath interference. However, due to computational complexities that hinder practical realization, the CORDIC algorithm has been employed to facilitate hardware implementation. The intricate matrix computations are executed by a systolic array comprising CORDIC processor element (CPE) cells, synchronized by a specific clock. The simulation results demonstrate that the adaptive equalizer surpasses the RAKE receiver's performance to a considerable extent in multipath fading channels. Furthermore, the system complexity is reduced since the channel estimation module can be omitted.

Reference

1. Boutros J. and Viterbo E., "Signal Space Diversity: A Power- and Bandwidth-Efficient Diversity Technique for the Rayleigh Fading Channel, IEEE Transactions on Information Theory, vol. IT-44, pp. 1453-- 1467, July 1998.
2. Eweda. E. "Comparison of RLS, LMS, and sign algorithms for tracking randomly time-varying channels." IEEE Trans. on Signal Processing, vol. 42, no. 11, pp. 2937-2944, Nov. 1994.
3. Hu Y. H., "CORDIC-based VLSI architecture for digital signal processing." IEEE Signal Processing Magazine, 9 (3): 16-35, 1992.
4. Ozan K. Tonguz, and Melanie M. Wang, "Cellular CDMA Networks Impaired by Rayleigh Fading: System Performance with Power Control", IEEE Trans. on Veh. Tech., Vol. 43, No. 3, August 1994.
5. 3GPP TS23.101 V3.5.0: “UE Transmission and reception (FDD)”, Release 1999
6. Proakis, J.G: "Digital Communications", Third Edition, McGraw-Hill Inc., 1995
7. Simon Haykin: “Adaptive Filter Theory", Third Edition, Prentice-Hall Inc.,1996