CORDIC based QRD-RLS Adaptive Equalizer for CDMA Systems

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Abstract The conventional RAKE receiver employed in CDMA system can not satisfy the desired demand when the propagation channel possesses a considerable number of paths and a deep fading that causes serious inter-user and inter-symbol interferences. This paper proposes a novel means of adaptive equalizer based on QRD-RLS algorithm to substitute the traditional RAKE receiver. Regarding the computational complexity of the RLS, the well-known CORDIC algorithm has been exploited and plays a key role in the hardware implementation of the new approach. The proposed RLS structure is simulated extensively under different channel parameters and performance is compared against conventional RAKE structure.

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

1. Introduction

The time-varying multipath propagation and the multiuser interference are the two important issues that limit the capacity and performance of a wireless communication system based on the code division multiple access (CDMA) technology. The commonly proposed schemes to deal with these two factors are to use transmitter power control, diversity technique and/or error control coding [1][2]. An alternative approach to combat the distortion brought by the channel characteristic and the multiuser interference is to replace the traditional RAKE receiver with an efficient equalizer using the adaptive algorithms such as Least-Mean-Square (LMS) and Recursive Least-Squares (RLS).

The original version of this chapter was revised: The copyright line was incorrect. This has been corrected. The Erratum to this chapter is available at DOI: [10.1007/978-0-387-35618-1_37](https://doi.org/10.1007/978-0-387-35618-1_37)

C. G. Omidyar (ed.), *Mobile and Wireless Communications*

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Regarding the time-varying Rayleigh fading channel which is typical for a practical mobile radio system, due to the limitation of number of RAKE fingers, it's hard to reach a satisfied system performance when the number of channel path increases and the channel coefficient changes quickly from time to time. In addition, the system complexity increases dramatically as more RAKE fingers have been appended and a channel estimation module must be included at the receiver side. Time Domain Equalizers based on LMS or RLS can be a solution to solve the issues related to multipath interference and errors due to channel estimation.

The RLS algorithm takes into account all the information that extend back to the initialization and updates the estimation of the tap-weight vector upon the arrival of new data, thus it is preferred over the LMS algorithm due to its superior convergence properties [3]. The orthogonal triangularization of the input matrix via QR-decomposition (QRD) has played a crucial role in RLS filtering. Such triangularization process can be realized through a series of Givens rotations, which is commonly employed to do the QR updating on a sample-by-sample basis [7]. Figure 1 shows the block diagram of the proposed RLS based adaptive equalizer structure for a CDMA receiver.

Figure1: Structure of RLS Adaptive Equalizer in a CDMA system

Armed with the fast developing VLSI technology, systolic array has become practically feasible when realizing the QRD-RLS in hardware implementation. The CORDIC (Coordinate Rotation Digital Computer) algorithm [4] has been introduced to perform the two-dimension vector rotation instead of the conventional Givens rotations. The main idea underlying this algorithm is to do phase shifting through a series of "micro-rotations" using a fixed set of elementary rotation angles. Through a proper choice of the elementary angles all computations can be implemented efficiently in VLSI using a sequence of shift and add/subtract operations. Generally, a look-up-table holding the elementary rotation angles is set up in advance to perform the phase shifting replacing the trigonometric functions

exploited in Givens rotations, which are not applicable in hardware realization.

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

This paper is organized as follows, section 2 briefly introduces the mathematical principles of the QRD-RLS algorithm and discusses its limitation due to the high computational complexity. The CORDIC algorithm will be depicted in section 3 and its implementation in hardware realization will also be included. Section 4 discusses the simulation studies.

2. QRD-RLS Algorithm

The basic idea underlying the RLS algorithm can be described in two processes:

1. We calculate the output of a transversal filter produced by a set of tap inputs and then try to obtain the error estimation by comparing the output with the desired response.
2. We find a method to minimize this error by adjust the tap weight of the transversal filter so that we can approach the desired response at the output.

Let $\mathbf{d}(n)$ be the desired response vector at time n , $\mathbf{u}(i)$ the input signal vector at time i and $\mathbf{w}(i)$ the tap weight we are looking for, and then the goal is to minimize the cost function:

$$E = \sum_{i=1}^n \lambda^{n-i} |d(i) - \mathbf{w}^H(i) \mathbf{u}(i)|^2 \quad (1)$$

where λ is the forgetting factor used to ensure that the effect brought by past signals is reduced or "forgotten".

Eq. (1) can be converted to a matrix format as follows:

$$\varepsilon = \|\mathbf{e}(n)\|^2 = \|\Lambda(n) \mathbf{d}(n) - \Lambda(n) \mathbf{A}(n) \mathbf{w}(n)\|^2 \quad (2)$$

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

$$\Lambda = \text{diag}(\lambda^{n-1}, \lambda^{n-2}, \dots, 1) \quad (3)$$

$$\mathbf{d}^H(n) = [d(1), d(2), \dots, d(n)] \quad (4)$$

$$\mathbf{A}^H(n) = [\mathbf{u}(1), \mathbf{u}(2), \dots, \mathbf{u}(n)] \quad (5)$$

Regarding Eq. (2), since the multiplication by a unitary matrix does not change the norm of one matrix, we apply the QRD to transform the weighted input signal matrix $\Lambda(n) \mathbf{A}(n)$ into an upper triangular matrix $\mathbf{R}(n)$, the first part to the right of Eq. (2) has been transformed simultaneously into two auxiliary matrices denoted by $\mathbf{P}(n)$ and $\mathbf{V}(n)$:

The CORDIC algorithm will be introduced to solve such problem since it utilizes a look-up-table to do the rotation through series of sub-rotations.

There are two modes of CORDIC algorithm: the “vectoring” mode, which is used to determine the phase and magnitude of the input vector and the “rotation” mode, which actually performs the rotation of the input vector. In order to execute the Givens rotations, “vectoring” mode is applied firstly to determine the angle to be rotated followed by the “rotation” mode rotating the vector through a set of sub-rotation for certain loops.

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

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

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

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

The pseudo-digits q_i are used to determine the direction of rotation according to the present value of z_i . Under the vectoring mode, z_i is set to zero during the initialization and q_i is decided by the position of the current vector $\tilde{\mathbf{v}}_i$ in the updating process, once the original vector has been rotated to the abscissa, the phase can be obtained by the value of z_n . Similarly, under the rotation mode, z_i is initialized by the angle desired for rotation and q_i is decided by the sign of current z_i in the updating process, once the loop ends, the vector $\mathbf{v}$ has been rotated by θ while z_i approaches zero.

3.2 Systolic array

Another fascinating feature of CORDIC is that the determination of the rotation angle takes the same number of clock cycles as does the actual rotation. This permits a systolic array of QRD-RLS filtering. CORDIC algorithm has been exploited here to realize the function of every small cell in the systolic array as shown in Figure 2.[7] There are two kinds of cells in the figure differentiated by their shapes. The cell is always defined as CORDIC processor element (CPE), with the round one working under “vectoring mode” and the square one working under “rotation mode”.

Figure 2: Structure of systolic array

4. Simulation results

The proposed system is extensively simulated for different channel parameters and the performance is compared against conventional RAKE receiver. The CDMA based transceiver structure used in the simulation is compliant to 3GPP standards [5]: using orthogonal variable spreading (OVSF) as channelization codes and a segment of Gold sequence as scrambling code. Pulse shaping filter has been included in the system to smooth the chip signal and discard higher frequency components. Two receiver side antennas have been utilized to improve the performance and a two-branch structure is employed to reduce the taps, which is set as 4, needed for the RLS equalizer. The channel model used in the downlink simulation system is a Rayleigh fading channel with 10 paths as denoted by L . The maximum delayspread is 20 chips. The Doppler frequency denoted by F_d is relatively low in the simulation thus the time-varying channel changes slowly. The processing gain has been set to 16 and the number of user has been set as the quarter respectively the 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. The simulation assumes perfect synchronization and no power control matters are employed.

Figure 3 shows the simulation results of the proposed system. The solid curve in every figure denotes the BER against SNR per bit through the

Rayleigh fading channel when the number of user is set to single (single-user bound) [6] , serving as a preference for comparison. It's obvious that the RLS equalizer outperforms the conventional RAKE by nearly 4 dB at the BER level of 10^{-2} in the case of quarter system load. It can be also observed easily that the system performance deteriorates as the number of user increases. However, the MUI caused by the increasing of the user number doesn't affect the equalizer as heavily as for the RAKE receiver. For both two cases, a noticeable error bottom can be observed for the RAKE receiver case but the performance for the RLS equalizer improves with Eb/No.

(a) quarter system load

(b) half system load

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

5. Conclusion

This paper has focused on a novel approach of signal receiving in CDMA system: replace the RAKE with an adaptive equalizer based on QRD-RLS algorithm due to its perfect convergence property and robustness against multipath interference. Considering the computational complexities, which hinder it from practical realization, the CORDIC algorithm has been introduced to make it feasible for hardware implementation. The complicated matrix computation has been carried out by a systolic array consisted of CPE cells and driven by a certain clock. It can be observed from the simulation results that the adaptive equalizer outperforms the RAKE to an ideal extent in a multipath fading channel and the system complexity has been reduced since the channel estimation module can be omitted.

Reference

- [1] 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.
- [2] J. Boutros and E. Viterbo, "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.
- [3] E. Eweda. "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.
- [4] Y. H. Hu, "CORDIC-based VLSI architecture for digital signal processing." IEEE Signal Processing Magazine, 9 (3): 16-35, 1992.
- [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