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A Simplified Single Correlator Rake Receiver for CDMA Communications

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Abstract— This paper presents a single correlator RAKE receiver for direct sequence code division multiple access (DS-CDMA) systems. In conventional RAKE receivers, multiple correlators are used to despread the multipath signals and then to align and combine those signals in a later stage before making a bit decision. The simplified receiver structure presented here uses a single correlator and single code sequence generator to recover the multipaths. Modified Walsh-Hadamard codes are used here for data spreading that provides better uncorrelation properties for the multipath signals. The main advantage of this receiver structure is that it requires only a single correlator and a code generator in contrary to the conventional RAKE receiver concept with multiple correlators. It is shown in results that the proposed receiver achieves better bit error rates in comparison with the conventional one for more than one multipaths.

Keywords— RAKE receiver, Code division multiple access, Modified Walsh-Hadamard codes, Single correlator.

I. Introduction

HIGH throughput, flexibility of design and dedicated network with integration of service, which constitutes the basic quality, reliability and service respectively, are becoming more challenging task in recent mobile communication systems. Code divisional multiple access (CDMA) is one such spread spectrum technique [1]-[4] that offers the potential of high spectrum efficiency, together with other features such as soft capacity, multipath resistance, and inherent frequency diversity. These factors have contributed to growing interest in this technology for broadband third-generation (3G) cellular mobile systems, as well as beyond 3G systems with adaptive processing capability [5].

Recently, direct sequence CDMA (DS-CDMA) has emerged as a technology for 3G wireless communication systems. In DS-CDMA systems [6], the transmitted signal is spread over a wide frequency band, much wider than the minimum bandwidth required to transmit the information being sent and the wireless bandwidth is allocated on demand, i.e., all users share the same wireless bandwidth and simultaneous transmissions affect each other through an increase in the random noise. Deployment of such wideband signals in the DS-CDMA systems for transmission produces a delay spread, which, in turn, gives rise to multiple versions of the transmitted signal. In order to mitigate the multipath fading, a diversity receiver is used in the DS-CDMA systems which achieves gain by combining multipath signal components with different delays, and is known as RAKE receiver [7]. The conventional present day RAKE receivers have multiple fingers, with each finger processing an assigned multipath. Each finger consists of despreading block, correlator, code generator and compensator. However, if the minimum resolution between any two multipath is taken as a chip duration, the multipaths might be resolved by time diversity with the help of a single correlator RAKE receiver [8]. For implementing such a receiver, it is necessary to substantiate the spreading code used in the scheme with a very low correlation property.

In this paper, a single correlator RAKE receiver is implemented with modified Walsh-Hadamard (MWH) codes for channelization, which yields minimum correlation between any two of them [9]. Few specific generator matrix patterns are used to generate such MWH codes to have minimal correlation properties. The proposed receiver structure focuses on de-spreading assuming that the de-scrambling is handled prior to de-spreading. Section II explains the conventional Rake receivers, Section III presents modified Walsh-Hadamard codes, Section IV presents the receiver structure with single correlator, Section V deals with the simulation results and Section VI draw some conclusions.

II. Conventional RAKE Receiver

A conventional RAKE receiver uses multipath diversity principle. It collects the energy in the multipath signals instead of suppressing them. RAKE receiver attempts to collect the time shifted versions of the original signal by providing a separate correlation receiver known as finger for each of the multipath signals. Each finger of the RAKE receiver has a separate code generator to generate codes with different phases, where each phase corresponds to a specific multipath. Fig.1 shows the block diagram of such a conventional RAKE receiver.

Here matched filter provides the impulse response measurements of the multipath channel profile, from which multipath delays are calculated and provided to different receiver blocks. The code generator of each finger is adjusted to generate a code sequence with a specific phase offset, which corresponds to the detected multipath. The generated code sequence is supplied to the correlator, which despreads the corresponding multipath. The correlation is obtained by multiplying the received sequence chips with corresponding chips of the spreading sequence and summing them up. Delay equalizer provides the time alignment of all the multipaths. Time aligned symbols are send for the maximal ratio combining, in which symbols are multiplied with complex conjugate of the channel

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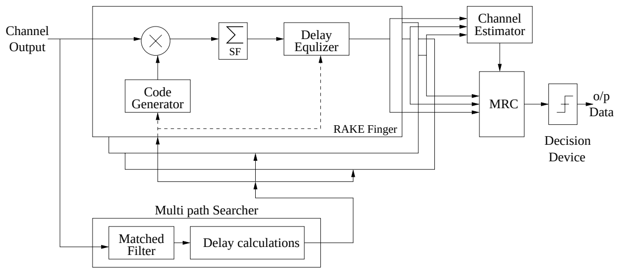

Fig. 1. Conventional RAKE receiver.

estimate and the result of multiplication is summed together into the combined symbol. Finally the bit decision is made using this combined symbol.

Usually, such a RAKE receiver uses Walsh-Hadamard codes for data spreading purpose. These codes, however, cannot guarantee minimum correlation between any two of them. A modified version of that is thus used in the proposed work, as discussed next.

III. Modified Walsh-Hadamard Codes

Walsh-Hadamard orthogonal functions are generally used for spreading in DS-CDMA systems. Orthogonal functions are employed to improve the bandwidth efficiency of the system. N number of Walsh-Hadamard functions are generated by mapping to the codeword rows of special $N \times N$ square matrix called Hadamard matrix. The Hadamard matrix of desired length can be generated by the following recursive procedure:

$$\mathbf{H_1} = \left[\ 1\ \right]_{1\times 1},\ \mathbf{H_2} = \begin{bmatrix} \mathbf{H_1} & \mathbf{H_1} \\ \mathbf{H_1} & -\mathbf{H_1} \end{bmatrix}_{2\times 2}, \ldots$$

$$\mathbf{H_N} = \begin{bmatrix} \mathbf{H_{N/2}} & \mathbf{H_{N/2}} \\ \mathbf{H_{N/2}} & -\mathbf{H_{N/2}} \end{bmatrix}_{N\times N}.$$

Walsh-Hadamard sequences have considerably high auto correlation values. In the presented receiver, output of the descrambling process is the sum of the delayed multipath spreading sequences with their corresponding path delays. Hence less auto correlation values are required for the better decisions. The modified Walsh-Hadamard sequences (MWH) are characterized with much lower auto correlation values [9] and are therefore used here.

The Walsh-Hadamard sequences of length N are defined with a class of orthogonal matrices $\mathbf{H_N}$, called Hadamard matices, as follows

$$\mathbf{H_N}\mathbf{H_N^T} = N\mathbf{I_N} \quad (1)$$

where $\mathbf{H_N^T}$ is the transposed Hadamard matrix of order N, and $\mathbf{I_N}$ is the $N \times N$ unity matrix. The modified Walsh-Hadamard sequences are taken from the matrix $\mathbf{W_N}$ obtained by multiplying the Hadamard matrix $\mathbf{H_N}$ with another $N \times N$ orthogonal matrix $\mathbf{D_N}$, i.e.,

$$\mathbf{W_N} = \mathbf{H_N}\mathbf{D_N}. \quad (2)$$

The matrix $\mathbf{W_N}$ is also orthogonal, since

$$\mathbf{W_N}\mathbf{W_N^T} = \mathbf{H_N}\mathbf{D_N}(\mathbf{H_N}\mathbf{D_N})^{\mathbf{T}} = \mathbf{H_N}\mathbf{D_N}\mathbf{D_N^T}\mathbf{H_N^T} \quad (3)$$

where it can be shown that

$$\mathbf{D_N}\mathbf{D_N^T} = k\mathbf{I_N}, \qquad k \in \mathbb{R}. \quad (4)$$

Substituting (4) into (3) yields

$$\mathbf{W_N}\mathbf{W_N^T} = k\mathbf{H_N}\mathbf{H_N^T} = kN\mathbf{I_N}. \quad (5)$$

If $k = 1$, then the sequences defined by the matrix $\mathbf{W_N}$ are not only orthogonal, but possess the same normalization as the Walsh-Hadamard sequences [9]. However other correlation properties of the sequences defined by $\mathbf{W_N}$ can be significantly different to those of the original Walsh-Hadamard sequences.

The simple class of orthogonal matrices that can be chosen is diagonal matrices, with their elements $(d_{m,n})$ fulfilling the condition:

$$d_{m,n} = \begin{cases} 0 & \text{for } m \neq n \\ k & \text{for } m = n \quad ; m,n = 1,2,\ldots,N. \end{cases}$$

For the sequence length N, 2^N different diagonal matrices with $+1$ and -1 as the elements are available to generate the modified sequences. Among these, however some diagonal matrices with specific arrangement of $+1$s and -1s give overall better auto-correlation properties. They are enlisted below.

(a)

$$d_{m,n} = \begin{cases} 0 & \text{for } m \neq n \\ -1 & \text{for } m = n = 4p \quad ; p = 1,2,\ldots,N/4 \\ 1 & \text{otherwise.} \end{cases}$$

(b)

$$d_{m,n} = \begin{cases} 0 & \text{for } m \neq n \\ (-1)^p & \text{for } m = n \text{ } and \text{ } p = 1,2,\ldots,N/2 \\ 1 & \text{otherwise.} \end{cases}$$

(c)

$$d_{m,n} = \begin{cases} 0 & \text{for } m \neq n \\ -1 & \text{for } m = n \quad ; m,n = 1,2,\ldots,N/4 \\ 1 & \text{otherwise.} \end{cases}$$

In CDMA systems, the number of chips per data symbol is called the spreading factor (SF). To represent a data symbol, each mobile user employs one of the N length orthogonal functions. Hence SF equals to length of codeword (N).

IV. Proposed Single Correlator RAKE Receiver with Modified Walsh-Hadamard Codes

The multipath wireless channel impulse response can be modeled as

$$\sum_{k=1}^{L} \alpha_k(t)\delta(t - \tau_k) \quad (6)$$

where $\alpha_k(t)$is the time-variant complex multipath gain, which is given by $|\alpha_k(t)|e^{j\phi_k(t)}$. Depending on the specific propagation environment, $\alpha_k(t)$ is a positive random variable with certain density function. Commonly used density functions include Rayleigh, Rician or more generally a Nakagami distribution, which comes from both theoretical derivation and field measurements. Among them, the Rayleigh density function is most widely used, which corresponds to non line-of-sight propagation and uniformly distributed scatters around the receiver. If we further assume that the phase $\phi_k(t)$ is independent of $|\alpha_k(t)|$ and is uniformly distributed over $[0\ 2\pi]$, then $\alpha_k(t)$ is a complex Gaussian random variable.

A sequence and its multipaths have same sequence pattern. If the minimum resolution between the multipaths is considered to be a chip, then they can be separated because of time diversity and low correlation values. The received signal can be modeled as

$$r[n] = r_{i=0}[n] + \sum_{i=1}^{\tau_{max}} r_i[n] + \sum_{i=-1}^{-\tau_{max}} r_i[n] \tag{7}$$

where $r[n]$ is the sequence transmitted in the channel, n represents the chip index, i denotes the delay in number of chips, and τ_{max} being the maximum delay in number of chips.

The above sequence model forms the basis for the single correlator structure design. The delay index $i = 0$ represents the sequence with no shift, while positive indices represents the sequences transmitted earlier and the negative indices represents multipaths of the sequence. In practical all components may or may not present. The CDMA communication model with single correlator RAKE receiver is shown in Fig. 2.

In the proposed single correlator, the spreading sequence is latched in a fixed register to eliminate the need of multiple code generators running continuously as in conventional RAKE receiver. A serial shift buffer of length equal to that of sequence is used to hold the received chips. As a new chip is received the buffer shifts and drops the oldest chip to accommodate the newest chip in the buffer. Multipath searcher detects the multipaths in the channel and provides the same to the code generator and maximal ratio combiner. Each chip of the serial shift buffer is connected through a multiplier with the corresponding chip of the code latch. These multipliers multiply the corresponding chips in the serial shift buffer and fixed register whenever multipaths are detected by the multipath searcher. Each multiplier output is buffered in its dedicated buffers and they are integrated by the adder.

Multipaths can be despread with the single correlator if the correlation process could be completed with in a single chip time. The same correlator could be reused to despread the next multipath which may be a chip later.If a multipath is detected after a chip later the results of multipliers in the buffers gets updated for single chip. So the adder should be able to add spreading factor number of buffer contents with in a single chip period.

Maximal-Ratio Combining is the optimal form of diversity combining because it yields the maximum achievable SNR. Multipath searcher passes the multipath information to the MRC. Maximal ratio combiner (MRC) collects all the integration results of a sequence and its multipaths to combine them for a bit decision.

In MRC integrated multipath components let $z_1(t), z_2(t), \ldots, z_L(t)$ are multiplied with complex conjugate of the channel characteristics.

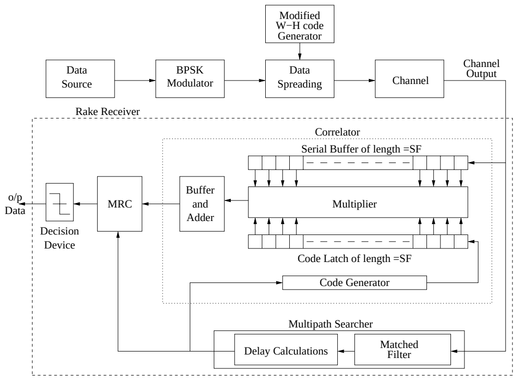

Fig. 2. CDMA communicational model with single correlator RAKE receiver.

Hence multipaths are weighted by $\alpha_1^*(t), \alpha_2^*(t), \ldots, \alpha_L^*(t)$ respectively. The output of the MRC can be given by

$$z^{'} = \sum_{k=1}^{L} \alpha_k^* z_k. \tag{8}$$

This output is send to the decision device for the bit decisions. The decision device decisions are based on the fallowing criteria:

$$\hat{d} = \begin{cases} 1 & \text{if } z^{'} > 0 \\ -1 & \text{if } z^{'} < 0\ . \end{cases} \tag{9}$$

Multipaths with delay spread longer than the length of the sequence are ignored, hence $\tau_{max} = N = SF$. MRC combines the integration results of multipaths detected till SF number of chips.

V. Results and Discussions

BPSK symbols are used for the simulations. These symbols are spread with the spreading code sequences. Impulse response channel model is used, in which multipaths are generated using Rayleigh fading channel characteristics. Noise is generated and added to the multipaths. All the multipaths are added together to simulate the signal at the receiver.

It is assumed that the channel characteristics and the delays are known at the receiver. As the multipath is detected integration process takes place. The integration results are stored for the maximal ratio combining. MRC combines the integration results and sent for bit decisions. The recovered binary data is decoded and probability of error is computed. Simulations have run with Walsh-Hadamard and modified Walsh-hadamard codes for same delays and data bits. It is assumed that no other user is occupying the channel hence multi-user interference is neglected.

It is observed that the whole set of modified Walsh-Hadamard codes generated with the proposed orthogonal matrices have better auto correlation properties and reduces the bit error rates (BER) compare to the Walsh-Hadamard codes. Fig. 3 shows the BER vs SNR plot with 16-bit length Walsh-Hadamard code for conventional RAKE receiver. Figures 4

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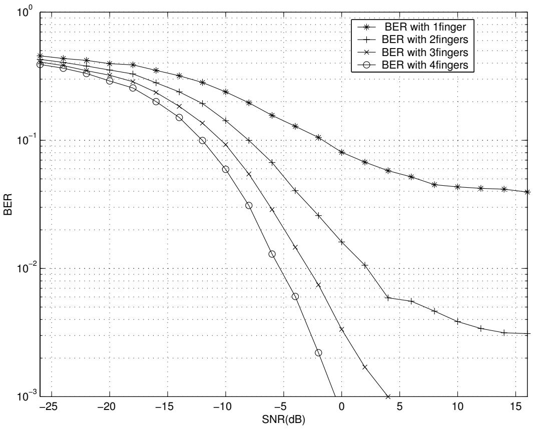

Fig. 3. BER plots with Walsh-Hadamard spreading code for the conventional RAKE receiver.

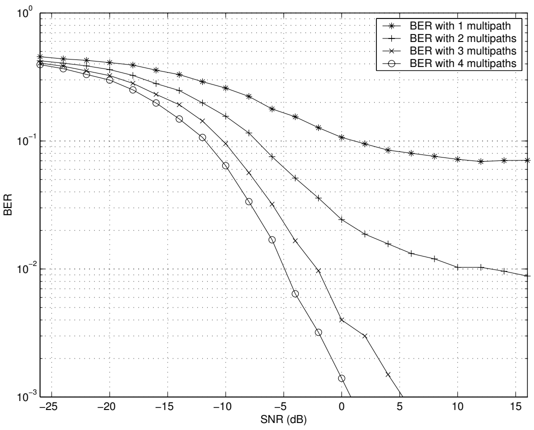

Fig. 4. BER plots with Walsh-Hadamard spreading code for the single correlator RAKE receiver.

and 5 show the BER vs SNR plots for single correlator RAKE receiver with 16-bit Walsh-Hadamard and modified Walsh-Hadamard spreading sequences respectively.

VI. Conclusions

A single correlator RAKE receiver with MWH codes as the spreading codes has been introduced. The presented single correlator RAKE receiver gives considerable better operation in comparison with the conventional RAKE receiver in terms of circuit complexity, power consumption and BER performance. In the presented single correlator structure, spreading sequence is latched as compared to multiple code generators running continuously in a conventional RAKE receiver. This gives an apprehensible reduction in complexity and power consumption, which are the major requirements in mobile communications. The MWH codes generated with mentioned diagonal matrices are characterized with lower correlation values. MWH codes as channelization codes in CDMA systems provide improved BER results compared to Walsh-Hadamard codes which is shown in the results.

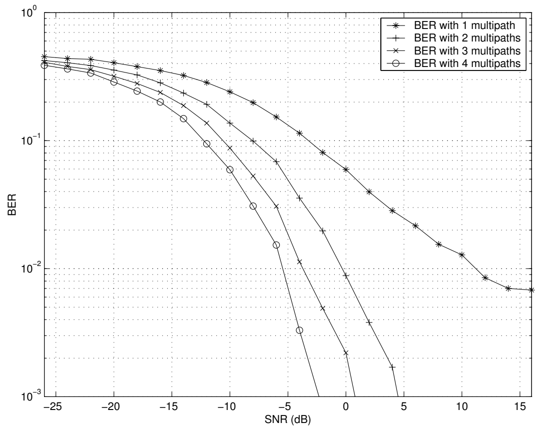

Fig. 5. BER plots with modified Walsh-Hadamard spreading code for the single correlator RAKE receiver.

References

[1] F. Adachi *et. al.*, "Broadband CDMA Techniques," *IEEE Wireless communications*, vol. 12, no. 2, pp. 8-18, Apr. 2005.
[2] R. Fantacci *et. al.*, "Perspectives for Present and Future CDMA-based Communications," *IEEE commun. Magazine*, vol. 43, no. 2, pp. 95-100, Feb. 2005.
[3] E. H. Dinan and B. Jabbari, "Spreading Codes for Direct Sequence CDMA and Wideband CDMA Cellular Networks," *IEEE Commun. Magazine*, vol. 36, no. 9, pp. 48-54, Sep. 1998.
[4] R. L. Pickholtz *et. al.*, "Theory of Spread-Spectrum Communications-A Tutorial," *IEEE Trans. Commun.*, vol. 30, no. 5, pp. 855-884, May 1982.
[5] S. Ohmori *et. al.*, "The Future Generations of Mobile Communications Based on Broadband Access Technologies," *IEEE Commun. Magazine*, vol. 38, no. 12, pp. 134-142, Dec. 2000.
[6] M. B. Pursley, "Direct-Sequence Spread-Spectrum Communications for Multipath Channels," *IEEE Trans. Microwave Theory and Techniques*, vol. 50, no. 3, pp. 653-661, Mar. 2002.
[7] R. Price and P. E. Green, "A Communication Technique for Multipath Channels," *Proc. IRE*, vol. 27, pp. 555-570, Mar. 1958.
[8] M. Uzzafer, "Single Correlator Receiver for Wideband MultiPath Channel," in *Proc. IEEE 6th CAS Symp.*, Shanghai, vol. 2, June 2004, pp. 421-424.
[9] B. J. Wysocki and T. A. Wysocki, "Orthogonal Binary Sequences with Wide Range of Correlation Properties," for *ISCTA'01*, Ambleside, U.K., July 2001, pp. 483-485.
[10] L. Harju *et. al.*, "A Flexible RAKE Receiver Architecture for WCDMA Mobile Terminals," for *SPAWC '01*, Taoyuan, Taiwan, Mar. 2001, pp. 9-12.
[11] S. Lee *et. al.*, "Low-complexity Architecture of RAKE Receiver for Multi-Code CDMA System," *IEE Electron. Lett.*, vol. 34, no. 14, pp. 1382-1383, July 1998.
[12] J. Cheng and C. Beaulieu, "Accurate DS-CDMA Bit-Error Probability Calculation in Rayleigh Fading," *IEEE Trans. Wireless Commun.*, vol. 1, no. 1, pp. 3-15, Jan. 2002.