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A PAPER ON DECISION FEEDBACK EQUALIZATION (DFE) WITH SPACE-TIME SPREADING (STS) IN WCDMA DOWNLINK CHANNEL

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ABSTRACT

In third generation commercial wideband code division multiple access (WCDMA) systems, orthogonal codes are used to spread transmitted signal in the downlink channel to accommodate different users. But, the frequency selective fading destroys the orthogonility and produces multiple access interference (MAI). One can use Rake receiver in the WCDMA downlink channel. Although a Rake receiver provides reasonable performance due to path diversity, it doe not restore the orthogonality. A linear equalizer followed by a spreader may be an attractive alternative receiver to restore the orthogonality and to suppress the MAI. However, the performance of a linear equalizer depends on the spectral characteristics of the channel and thus may not be satisfactory for some channels. To overcome this difficulty, a decision feedback equalizer (DFE) can be used. In this paper, we have investigated a decision feedback equalizer (DFE) for WCDMA downlink channel with multiple antennas. The work includes the design of the DFE when the space-time spreading scheme is employed at the transmitter. Simulation results show significant performance gains compared to the Rake receiver and the linear equalizer.

Keywords : *Decision feedback equalizer (DFE), Wideband Code Division Multiple Access (WCDMA), Rake receiver, multiple access interference (MAI).*

1. INTRODUCTION

Recent advances in communications are driven by the requirements of next-generation wireless systems to provide high data rate and high quality services anywhere at anytime. But the spectrum continues to be scarce and expensive, which creates new challenges in the development of telecommunication systems [1]. The increasing demand for very high capacity data rates and quality of services for wireless communications systems require wideband wireless systems with reliable links. Wireless cellular systems are known to suffer from fading and intersymbol interference (ISI) caused by multipath propagation, which may degrade the system performance significantly. Therefore, the effective and efficient interference mitigation is required for a high quality signal reception. A major factor limiting the capacity of wireless channels is the unreliability due to slow fading, which is generally treated by increasing the degrees of freedom in the system, especially by means of multiple antenna diversity. The multiple antennas at both transmitter and receiver ends can effectively improve the quality of the wireless link by giving advantage in space diversity. Improvement of downlink capacity is one challenge facing the effort toward third generation wireless system. In commercial wideband code division multiple access (WCDMA), the transmitted signal in the downlink channel is spread by orthogonal codes. [2]. In a flat fading channel where the propagation delay of multipath signal is negligible, a simple desperader is sufficient to suppress multiple access interference (MAI) resulting from the effects of the interference from other users within a cell. However, once we have a frequency selective fading channel, the orthogonality cannot be retained. Therefore, MAI exists at the output of the despreader and the performance degrades.

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We can design a receiver to improve the performance by mitigating multipath fading for the WCDMA downlink channel. For instance, the RAKE receiver can be used to get path diversity [3]. Although, a RAKE receiver can provide reasonable performance due to path diversity, its performance is still limited by MAI, the numbers of multipaths, power control in the downlink channel, and channel estimation error. Because of this, better approaches such as MAI suppression must be considered. Many innovative receivers have been proposed to suppress MAI. Multiuser detection techniques that use joint code, timing and channel information can be employed to improve performance by mitigating MAI [4-5]. Although multiuser detection techniques out perform the RAKE receiver, the complexity is high. Therefore, it is impractical to apply these techniques in mobile terminals due to computing constraints.

Equalization can be adopted to restore orthogonality without significantly increasing the complexity. Then, a despreader can suppress MAI from the orthogonal signal. A linear equalizer (LE) restores the orthogonality of the chip sequence and performs better than the RAKE receiver [6-8]. However, if the channel equalization is not perfect, the performance of a linear equalizer is degraded by MAI.

We can consider a more powerful receiver algorithms in the form of a decision feedback equalizer. A decision feedback equalizer (DFE) [9] can have better immunity against spectral channel characteristics, reduce the noise enhancement effect, shorten the length of equalizer tap, and give the forward linear filter greater flexibility in handling intersymbol interference (ISI) resulting from the interference from other symbol at the sampling instant. Hence, the DFE outperforms the LE. The standard DFE for nonspread signal has been considered in many papers [10].

To improve the performance further, multiple-input multiple output (MIMO) channels (by using multiple antennas) can also be employed [11]. MIMO channels can provide additional diversity gain to the mobile station and thus, can improve the performance. Different schemes such as space-time spreading [12] were developed to achieve diversity gain in CDMA systems.

Space-time spreading (STS) [12] spreads each signal in a balanced way over the transmitter antenna elements to provide maximal path diversity at the receiver. The simplest STS scheme is when each user is assigned with a different orthogonal code for each transmit antenna.

A DFE based on the minimum mean square error (MMSE) criterion [10] for nonspread signals in multiple antennas has been derived in literatures [13]. An MMSE-DFE has better performance when compared to the MMSE-LE, especially with the highly dispersive and non-minimum phase characteristic channel. In this paper, we investigate a decision feedback equalizer (DFE) based on space-time spreading (STS) scheme. We apply the DFE for a WCDMA downlink channel using STS scheme in single-input single output as well as in multiple-input multiple output channels. Simulation results show significant performance improvement on a WCDMA downlink channel compared to RAKE receiver.

2. Conventional decision feedback Eqqualizer (DFE)

We first investigate the standard decision feedback equalizer (DFE) receiver for a nonspread signal. A DFE is a nonlinear equalizer that employs previous decisions to eliminate the intersymbol interference (ISI) caused by previously detected symbols on the current symbol to be detected [9]. Figure 1 shows a base band model for the standard DFE. The DFE consists of a feed forward filter c[m] and a feedback filter g[m], where m is the symbol index. Because the feedback filter sits in a feedback loop, it must be strictly causal. The signal propagates through a discrete time-variant frequency selective fading channel h[m]. Let P be the number of channel multipath, and the complex channel is assumed time-invariant, *i.e.* $h[p; m] = h[p]$ for $p = 1, \ldots, P$. The received signal $r[m]$ can be written as

$$r[m] = \sum_{p=0}^{P-1} h^* [p]\, b[m - p] + h[m] \qquad \ldots (1)$$

Where $b[m]$ is the transmitted symbols information, $\{h[p]\}$ is the discrete channel impulse response, $n[m]$ is the additive white Gaussian noise with mean zero and variance σ_n^2.

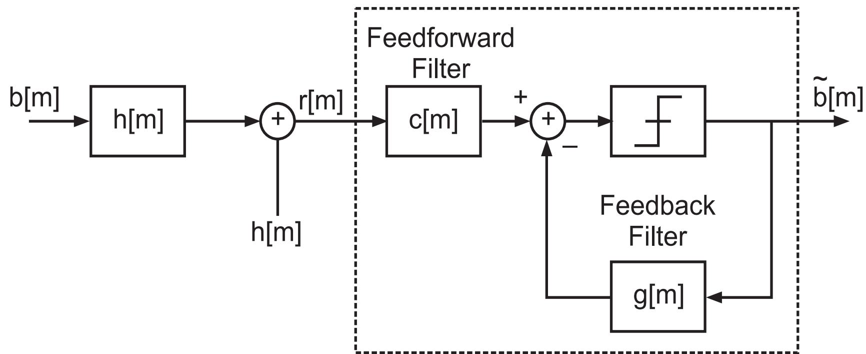

Figure 1 : The conventional DFE structure

3. Decision feedback equalizer (DFE) with the STS Scheme

In this section, we investigate the performance of a DFE for WCDMA downlink channel when the STS scheme is employed at the transmitter. In the STS scheme, a set of different orthogonal codes is assigned to multiple transmit antennas for each user. In principle, any number of transmit antennas can be employed as long as we have a sufficient number of distinct orthogonal codes. In order to estimate channels, the pilot signals are utilized. It is assumed that each antenna continuously transmits its pilot signal (*i.e.,* code multiplexed pilot is assumed). Let us consider that the base station employs user specific orthogonal Walsh-Hadamard spreading codes and a site-specific base spreading codes. We assume perfect carrier recovery at the receiver site and there are K users in a WCDMA downlink channel.

Let us also consider I transmit antennas and J receive antennas. Each transmit antenna transmits different pilot signals using different orthogonal spreading sequences. Each user is assigned with a different orthogonal spreading codes for each transmit antenna.

Let $u^{(i)}[n]$ be the total base band transmission signal, transmitted from antenna *i* at the base station. The received signal at the *j*th receive antenna is written as

$$r^{(j)}[n] = \sum_{i=1}^{I} \sum_{p=0}^{P-1} h_{ji}^{*}[p]\, u^{(i)}[n-p] + \eta^{(j)}[n] \quad \ldots (2)$$

Where

$$u^{(i)}[mN+l] = \sum_{k=1}^{K} u_k^{(i)}[mN+l], + u^{-(i)}[mN+l]$$

$$u_k^{(i)}[mN+l] = a_k b_k[m] s_k^{(i)}[mN+l]$$

$$u^{-(i)}[mN+l] = \overline{ab}[m]\; s^{-(i)}[mN+l]$$

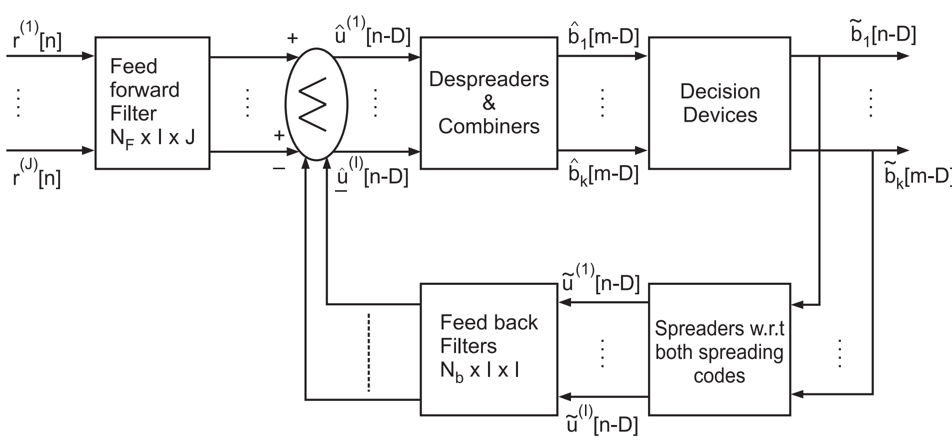

Figure 2 : The DFE based on the STS scheme with J receive

In the vector notation, the $J \times 1$ received signal vector can be written as

$$r[n] = \sum_{i=1}^{I} \boldsymbol{H}_i^H \boldsymbol{u}^{(i)}[n] + \boldsymbol{n}[n]$$

Where the channel matrix H_i, the received signal vector $\mathbf{r}[n]$, the transmitted signal vector is $u^{(i)}[n]$ and the noise vector is $\mathbf{n}[n]$. Figure 2 shows the block diagram of DFE with the STS scheme. A DFE with the STS scheme consists of a feed forward filters c_{ij} with a temporal span of N_f taps and a feedback filters g_{ii} with a temporal span of N_b taps. We also assume that the decision delays are the same for every data stream, *i.e.,*

$D_i = D$ for $i = 1, \ldots, I$.

The forward filter of the DFE with STS scheme works on maximizing the desired user's energy and minimizing the effects of existing interference in the channel using the MMSE criterion. On the other hand, a RAKE receiver combines the energies of the desired user received through the multipath channel without taking into account the presence of interferes. Also, the structure of the feedback filter of DFE with STS scheme is different from the conventional DFE. For the conventional DFE, the input signal to the feedback filter is a nonspread (symbol) signal. For the modified DFE with STS scheme, the input signal to the feedback filter is spread (chip) signal. The objective of the modified DFE is to estimate the chip rate sequence $u^{(i)}[n]$, $i = 1, \ldots, I$, from which the desired symbol sequence $b_k[m]$ is recovered by despreading the estimated chip rate sequence using the desired user's spreading sequence.

The total output of the DFE with the STS scheme is

$$\hat{u}^{(i)}[n-D] = W_i^H \, d[n]$$

Where W_i and $d[n]$ are the complete equalizer vector and complete data vector, respectively, and they can be written as :

$$W_i = (\boldsymbol{C}_i^T \ \boldsymbol{g}_i^T)^T$$

$$d[n] = (\Omega^T[n] - \boldsymbol{u}^T[n-D-1])^T$$

Let us denote:

$$Z_i[m] = \sum_{l=0}^{N-1} d[mN + l + D] \ s^{-*(i)}[mN + l]$$

Then, the MSE function of the modified DFE-despreader can be written as :

$$MSE_i = (|\bar{b}[m] - \boldsymbol{W}_i^H \boldsymbol{Z}_i[m]|^2), \quad i = 1, 2, .., I$$

4. Simulation Environments

In simulation work, we have used MATLAB to perform Monte Carlo Simulation. We consider single antenna systems and multiple antenna (MIMO) systems. For the MIMO system, two transmit and two receive antennas are employed. Time-variant frequency selective fading channels with 4 multipaths using Jakes model are considered. The carrier frequency is assumed to be 2 GHz and the speed of the mobile is set to 60 km/hr. The spreading sequences from the Walsh codes of length 32 and scrambling are used. The data rate is set to 128 Kbps and the chip rate is set to 4.096 Mcps.

The transmission powers are assumed to be the same with a SNR of 10 dB. The number of users K is set to 16. The orthogonal pilot signals in each transmit antenna are continuously transmitted. For signaling purpose, we use uncoded quadrature phase shift keying (QPSK). The tap numbers in feed forward and the feedback filters for the DFE based on the STS scheme are set to 5 and 3 respectively. The filter tap numbers have been properly decided to achieve the best performance and they depend on the variation of the channel and the SNR. For the performance indicator, the bit error rate (BER) is used. The average BER over all users has been computed. In order to handle the problems caused by channel variations, we consider the NLMS algorithms.

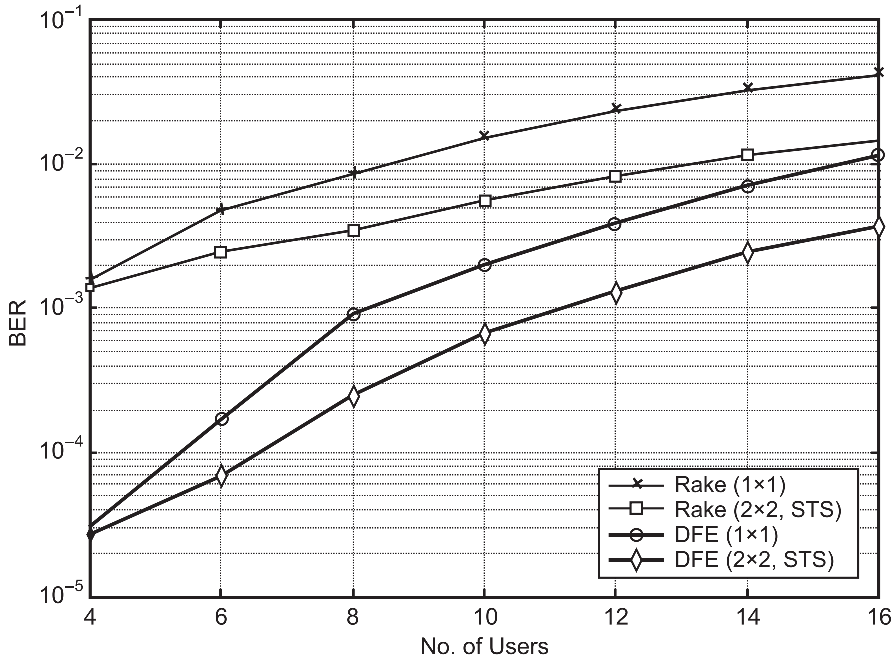

Figure 3 : BER performance of the DFE based on the STS scheme with respect to the number of users using the NLMS adaptation algorithm

5. Simulation results of the DFE with the STS scheme

In figure 3, the BER performance with respect to the number of users using the NLMS adaptation algorithm is shown. As the number of transmission increases, the performance for all receivers (the RAKE and the DFE) becomes worse due to increasing MAI. Since the equalization is not perfect under a time-variant fading environment, it is observed that the equalizer is also affected by the MAI. However, the DFE generally out performs the RAKE receiver. From figure 3, it can loss be observed that the significant BER improvement for both the RAKE receiver and the DFE can be achieved when multiple antennas are used.

6. CONCLUSION

In the paper, we have investigated and compared the performance of (DFE) with STS scheme. The study has demonstrated that significant improvement in performance and capacity can be made when the DFE based on the STS scheme is used. The improvement can be achieved since the receiver design exploits the diversity gain and suppresses the MAI at the same time. However, this receiver requires extra spreading codes. Using an MMSE cost function; the optimal equalization vector and the closed form expression have also been obtained. It is shown that ICI of a channel and the interfering signal from the other transmit antennas can be suppressed simultaneously. Comparing the performance of the DFE in the STS scheme for WCDMA downlink channel e with the RAKE receiver equipped with multiple antennas, the proposed method not only provides antenna diversity gain, but also suppresses MAI, while the RAKE receiver can only have antenna diversity gain. Therefore, the proposed method can offer significantly improvement in performance and capacity.

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