Chip level decision feedback equaliser for CDMA downlink with space-time coding

A. Santoso, J. Choi, C.C. Lim and B. Vucetic

In most commercial wideband code division multiple access systems, the transmitted signal in the downlink channel is spread by orthogonal codes to accommodate different users. However, frequency selective fading destroys the orthogonality and causes multiple access interference. Application of a chip level decision feedback equaliser with the Alamouti transmit diversity scheme is proposed to restore the orthogonality of the received spreading sequences.

Introduction: In most commercial wideband code division multiple access (W-CDMA) systems, the transmitted signal in the downlink channel is spread by orthogonal codes to accommodate different users [1]. However, frequency selective fading destroys the orthogonality and causes multiple access interference (MAI). Therefore, the MAI exists at the output of the despreader and the performance degrades.

One can design a receiver to improve the performance by mitigating multipath fading for the CDMA downlink channel. For example, the rake receiver can be used to obtain path diversity [2]. Although the rake receiver can provide reasonable performance by exploiting path diversity, its performance is still limited by MAI. Consequently, better approaches that are able to suppress MAI are considered.

The orthogonality can be exploited for memory channels. The equalisation followed by the despreader can be adopted to restore the orthogonality and then to suppress the MAI without significantly increasing the complexity. The chip level linear equaliser (LE) restores the orthogonality of the chip sequence and performs better than the rake receiver [3]. However, if the channel equalisation is not perfect, the performance of the chip level LE is degraded by the MAI. Moreover, the performance of the chip level LE still depends on the spectral characteristic of the channel and may not be satisfactory for some channels.

When searching for more powerful receiver algorithms, one might consider the decision feedback equaliser (DFE). The DFE can have better immunity against the spectral channel characteristics, reduce the noise enhancement effect, shorten the length of the equaliser tap, and give the forward linear filter greater flexibility in handling intersymbol interference (ISI). Thus, the DFE generally outperforms the LE. The chip level DFE for a CDMA system with a single transmit and receive antenna that uses long spreading sequences has been studied in [4].

In this Letter, we apply the chip level DFE for CDMA downlink channel with the Alamouti scheme [5] in multiple-input multiple-output (MIMO) channels. The chip level DFE exploits the benefits of MAI suppression and additional diversity gain. Simulation results show significant performance gains on a CDMA downlink channel compared to the rake receiver.

System model: Let us consider the discrete time complex baseband model for a downlink channel of a single cell direct-sequence CDMA system. The base station employs user specific orthogonal Walsh–Hadamard spreading codes and a site specific base spreading code. The Alamouti transmit diversity scheme with two transmit antennas [5], as shown in Fig. 1, is employed. There are K users in the system. For the coherent combining and channel estimation at the receiver, as shown in Fig. 1, two different orthogonal pilot spreading sequences ($\bar{s}^{(i)}[mN+l]$, $i=1, 2$) with different pilot symbols ($\bar{b}^{(i)}[m]$, $i=1, 2$) can be transmitted through two transmit antennas. Thus, the total baseband transmission signal $u^{(i)}[n]$, transmitted from antenna i at the base station can be written as:

$$u^{(i)}[mN+l] = \sum_{k=1}^{K} A_k b_k^{(i)}[m] s_k[mN+l] + \bar{A}_i \bar{b}^{(i)}[m] \bar{s}^{(i)}[mN+l]$$
$$i = 1, 2 \quad m = -\infty, \ldots, 0, \ldots, \infty \quad l = 0, 1, \ldots, N-1 \qquad (1)$$

where $\bar{A}_i$ is the amplitude of the pilot for transmit antenna i, $\bar{b}^{(i)}[m]$ is the pilot symbol for transmit antenna i, $\bar{s}^{(i)}[mN+l]$ is the pilot spreading sequence for transmit antenna i, A_k is the amplitude of user k, $s_k[mN+l]$ is the kth user spreading sequence, $b_k^{(i)}[m]$ is the data symbol to be transmitted through transmit antenna i to the kth user, m is the symbol index, $n = mN+l$ is the chip index, N is the processing gain, and l is the chip index within a symbol period.

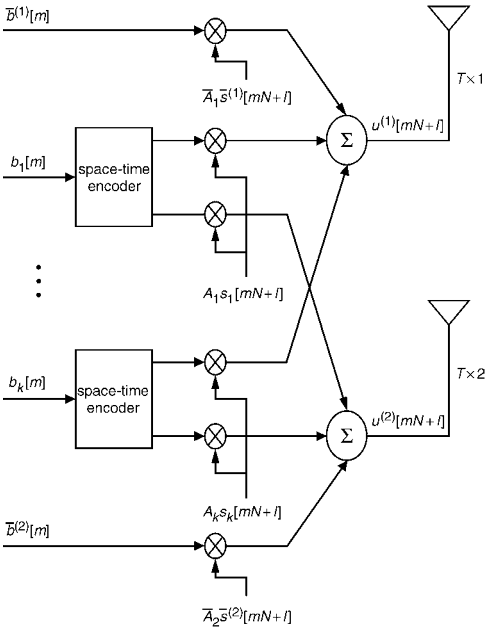

Fig. 1 *Block diagram for transmitter with Alamouti scheme*

Let Q and P be the number of receive antennas and the number of resolvable channel multipaths, respectively. The total baseband transmitted signals from each transmit antenna propagate through time-invariant frequency selective fading (multipath) channels $h_{qi}[p]$. Thus, the received signal at the qth receive antenna can be written as:

$$r^{(q)}[n] = \sum_{i=1}^{2} \sum_{p=0}^{P-1} h_{qi}^{*}[p] u^{(i)}[n-p] + w^{(q)}[n] \qquad (2)$$

where x^* is the complex conjugate of x, $w^{(q)}[n]$ is the additive white Gaussian random noise sequence of the qth receive antenna with mean zero and variance σ_n^2.

Chip level DFE with Alamouti scheme: Here we propose the chip level DFE for the Alamouti transmit diversity scheme [5]. The chip level DFE can bring the signals closer to orthogonal. In the feedforward path, the despreaders suppress the MAI after equalisation and then the space-time combiners are applied to combine the space-time encoded signal. In the feedback path, the space-time encoder is used to encode the decision symbol, and the spreaders follow to provide the spread (chip) signal to the feedback filter. Let us assume that previous decisions are correct. Thus, the optimum equaliser vector is:

$$\boldsymbol{c}_i = \boldsymbol{B}^{-1}\boldsymbol{v}, \qquad i = 1, 2 \qquad (3)$$

where $\boldsymbol{B}$ and $\boldsymbol{v}$ are given by:

$$\boldsymbol{B} = E\left(\sum_{l=0}^{N-1} \sum_{l'=0}^{N-1} \boldsymbol{d}[mN+l+D] \bar{s}^{*(i)}[mN+l] \right.$$
$$\left. \times \bar{s}^{(i)}[mN+l'] \boldsymbol{d}^{H}[mN+l'+D] \right) \qquad (4)$$

$$\boldsymbol{v} = E\left(\sum_{l=0}^{N-1} d[mN+l+D] \bar{s}^{*(i)}[mN+l] \bar{b}^{*(i)}[m] \right) \qquad (5)$$

and $E(\cdot)$ is the expectation function, $\boldsymbol{d}[mN+l+D]$ is the received signal vector to the feedforward and feedback filters, D is the decision delay, and H is the Hermitian transpose operator.

The minimum mean square error (MMSE) solution can be written as:

$$MMSE_i = \sigma_b^2 - \sigma_b^2 \bar{A}^{*}[(\bar{\boldsymbol{H}}_i)_{D+1} \boldsymbol{0}]\boldsymbol{c}_i, \qquad i = 1, 2 \qquad (6)$$

where σ_b^2 is the variance of data symbol, $\boldsymbol{0}$ is the null matrix, and $\bar{\boldsymbol{H}}_i$ is the channel matrix with $(P+N_f-1)$ rows and QN_f columns, N_f is the length of the feedforward filter, and $(\cdot)_{D+1}$ is the $(D+1)$th row of the corresponding matrix.

In the time-invariant channel, (6) shows that MMSE improves when the number of equalisation vectors increase. The equalisation vectors of the chip level DFE minimise the effects of interference, fading, multipath and AWGN.

Simulation studies: In this Section, the performance of the rake receiver and the adaptive chip level DFE is investigated and compared under various simulation environments. For the multiple antenna case, two transmit and two receive antennas are employed. Time-variant frequency selective fading channels with four multipaths using Jakes model are considered. The carrier frequency f_c is assumed to be 2 GHz and the speed of the mobile is set to 60 km/h. The spreading sequences from the Walsh codes of length 32 with scrambling are used. The data rate is set to 128 kbit/s and the chip rate is set to 4.096 Mc/s.

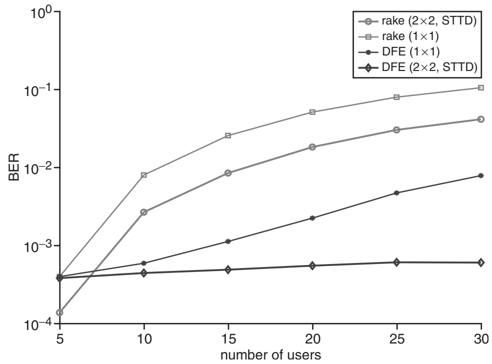

Fig. 2 *BER performance of chip level DFE based on Alamouti scheme against number of users using RLS adaptation algorithm*

The transmission powers are assumed to be the same, with signal to noise ratio (SNR) of 10 dB. The number of users K is set to 16. The signal amplitudes are the same, i.e. $A_k = \bar{A}_i = 1$; $i = 1, 2$. The orthogonal pilot signals in each transmit antenna are continuously transmitted. For signalling, we use uncoded quadrature phase-shift keying (QPSK). The tap numbers in the feedforward and feedback filters for the chip level DFE are set to 7 and 4, respectively. The optimum forgetting factor λ for the chip level DFE is set to 0.97. Note that the filter tap numbers and the forgetting factor have been properly decided to achieve the best performance, and that they depend on the variation of the channel and the SNR. In addition, the correct feedback is assumed for the chip level DFE and the perfect channel state information (CSI) for the rake receiver. 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 the channel variations, we consider the recursive least square (RLS) algorithms.

In Fig. 2, the BER performance with respect to the number of users using the RLS algorithm is shown. As the number of transmissions increases, the performance for all receivers (the rake and the DFE) becomes worse due to increasing the MAI. Since the equalisation is not perfect under a time-variant fading environment, it is observed that the equaliser is also affected by the MAI. However, the chip level DFE outperforms the rake receiver for the larger number of users since the chip level DFE can suppress interchip interference (ICI) more efficiently. For example, at a BER of 10^{-3}, the rake receiver with multiple antennas can accommodate only one-quarter of the system load, while the chip level DFE based on the Alamouti scheme can accommodate a full system load. A significant capacity improvement for both the rake receiver and the chip level DFE can be achieved when multiple antennas are used [6].

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