COMPARATIVE PERFORMANCE OF DIFFERENT ADAPTIVE CDMA FORMS ON DISPERSIVE CHANNELS

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Abstract: Spread spectrum techniques have been used for many cellular communication systems, and are being adopted widely for military communication networks. The motivation for employing this technique is its ability to suppress fading due to multipath propagation. In this paper, receivers based on chip level equalization are considered for a downlink code division multiple access (CDMA) system employing user-specific long or short spreading sequences to ensure good performance at low signal-to-noise ratios (SNRs). Adaptive turbo architectures for joint parameter estimation and multiple-access interference cancellation integrate the functions of equalization, multi-access interference cancellation, error correction and phase-carrier tracking. A direct adaptive CDMA receiver uses continuous pilots as training data and the filter coefficients are optimized based on the minimum mean square error (MMSE) criterion to suppress noise, ISI, and multiple access interference (MAI) with reasonable system complexity. Moreover, the proposed detectors with continuous pilots operate just in a tracking mode after the initial delay acquisition is accomplished. By exploiting the presence of a continuous pilot signal in the entire transmitted frame, this approach is well suited to tracking fast fading channels. The receivers are compared with Rake multiuser receiver-based channel estimation (CE) techniques using data obtained from experimental trials in the North Sea. Furthermore, three simultaneous users are reliably acquired and demodulated using a few stages. These results show that the direct adaptive receivers in both types of CDMA exhibit better immunity against the spectral channel characteristics and significant performance improvement over CE based receivers.

Keywords: Long code CDMA, Short code CDMA, Underwater Communication.
1. INTRODUCTION

Spread spectrum systems (SSS) show significant potential for underwater acoustic communications. In these systems, the data to be transmitted is multiplied by a spreading sequence and the use of different signatures allows multiuser transmissions. The system is known as short code CDMA, if the spreading sequences assigned to users are periodic or remain the same for all symbols. In long code CDMA, they are periodic or essentially pseudorandom and vary for the different transmitted symbols. By sharing these sequences, reliable simultaneous communication may exist in the same bandwidth. Additionally, the large bandwidth signals improve the immunity against the channel effects by discriminating the different paths at the reception [1].

Unlike deep-water propagation, where the signal arrivals include only the dominant path and surface bounce, fading in shallow-water channels is caused by closed paths that include many rays of similar amplitude arriving close together. The interactions of these arrivals with the surface further complicate propagation and increases time variability [2]. In multiuser CDMA systems, these effects and the MAI signals are the major problems to signal detection and separation. Therefore, in order to avoid performance degradation, multiuser detectors (MUD) can be used and significant improvement can be obtained where the MAI signal is explicitly part of the signal model. In IDMA systems [3], joint chip level equalization and detection has proven to be one of the most attractive receivers. These detection algorithms are used in [4] with semi-blind channel estimation for short and long spreading CDMA systems. In this paper, the sub-optimal detectors in [5] are used for CDMA detection signals with large complexity savings. These receivers do not need a multiplexed training sequence, which was the case for the system presented in [5], and use only a unique continuous pilot approach in the network.

2. SYSTEM DESCRIPTION

The information bits, $b_i(n)$ of user $k$ in Fig.1, are encoded by a rate 1/2 convolutional encoder, producing the encoded bit sequence. The encoded bits, after bit level interleaving $I$, are modulated using QPSK mapping and then scrambled using user-specific spreading sequence $S$ of length 8 bits. Since the downlink is being considered, all users’ signals are synchronously transmitted with a continuous pilot sequence on the same channel.

The SISO multiuser detector in Fig.1 takes soft information $r(n)$ and, after some processing, delivers refined a posteriori log-likelihood ratios (LLRs), $L_n[x_i(n)]$. The outputs after despreading and deinterleaving are sent to the decoders (DECs). The $k^{th}$ user decoder output $L_n[x_i(n)]$ after interleaving and user-specific spreading is subtracted from $L_n[x_i(n)]$ to form the extrinsic information of the $k^{th}$ user as follows

$$L_x[x_i(n)] = L_n[x_i(n)] - L_q[x_i(n)]$$

This soft information is passed to the detector for the next turbo pass. Then, by the turbo-principle, the soft information is greatly enhanced and the process stops after a predetermined number of iterations or specific convergence criteria. In general, multiuser receivers may simultaneously decode data from all users or may sequentially decode and then remove the signals from other interfering users.
2.1 SOFT RAKE MULTIUSER CDMA RECEIVER

The detector combines the peaks of all paths $L$ together instead of considering them as a harmful phenomenon with multiple access cancellation concepts to improve the performance. Due to cross-correlations between spreading sequences, there is interference after the multiuser detector and despeading operation. Therefore, by using a Gaussian approximation, $L_{m}[x_{j}^\prime(n)]$ of the real part of $x_{j}^\prime(n)$ can be computed as

$$L_{m}[x_{j}^\prime(n)] = 2|\hat{h}_{j}| \frac{\tilde{r}(n+l) - E[\tilde{\eta}_{j}^\prime(n)]}{\text{var}[\tilde{\eta}_{j}^\prime(n)]}, \quad \forall k,n$$  \hspace{1cm} (2)

$$L_{m}[x_{j}^\prime(n)] = \sum_{l=0}^{L} L_{w}[x_{j}^\prime(n)]_{l}, \quad \forall k,n$$ \hspace{1cm} (3)

where $\tilde{r}(n+l) = h_r r(n+l)$, $E[\tilde{\eta}_{j}^\prime(n)]$ and $\text{var}[\tilde{\eta}_{j}^\prime(n)]$ represent the mean and variance of the interference $\tilde{\eta}_{j}^\prime(n)$, respectively. The benefits from the spread spectrum signal are conditioned on the receiver’s ability to track the channel variations.

The semi-blind channel estimation algorithm in [4] with continuous pilots is used to estimate $\hat{h}(n)$. The adaptive process can be any adaptation algorithm and the phase update is also optimized jointly using a classical phase tracking approach. The adaptive estimation is refined with the combination of the pilot sequences, which are inserted into the feedback estimate stream to give information at each time instant and the updated soft estimates, which are assumed to be correct. Since the pilot sequence does not take part in the detection, it is removed before detection.
2.2 DIRECT ADAPTIVE DFE-CDMA RECEIVER

The receiver uses a combined adaptive equaliser with a carrier phase estimator based on MMSE filtering and a parallel interference detector followed by a single user's decoder. The output signal of a chip-level equalizer is the total users' signals. A feedback filter employing previous symbol decisions is added to eliminate the ISI on the current symbol being detected, transforming the linear receiver into a decision-feedback equaliser (DFE). The equalizers rely on prior knowledge of the previous signal that is not easily available since the constellation of all users’ signal sum is a high-order constellation. By using the central limit theorem and removing the training sequence, the remaining interference signal in $z(n)$ with respect to user $k$ can be modelled as a Gaussian random variable. Therefore, $L_n[x'_k(n)]$ of the real part of $x'_k(n)$, can be estimated as

$$L_n[x'_k(n)] = \frac{2[z'_k(n) - E[z'_k(n)] + E[x'_k(n)]]}{\text{var}[z'_k(n)] - \text{var}[x'_k(n)]}, \quad \forall k, n$$  \hspace{1cm} \text{(4)}$$

with

$$E[z(n)] = \sum_{i=1}^{K} E[x_i(n)], \quad \forall n$$  \hspace{1cm} \text{(5)}

and

$$\text{var}[z(n)] = \sum_{i=1}^{K} \text{var}[x_i(n)] + \sigma_w^2 \quad \forall n$$  \hspace{1cm} \text{(6)}$$

$L_n[x'_k(n)]$ is used to calculate the a priori means, $E[x'_k(n)]$, and variances $\text{var}[x'_k(n)]$ of the transmitted signal $x'_k(n)$. The weight vector for the feed forward section of the equalizer and for the feedback section of the equalizer, are updated once per symbol to track the rapid fluctuations in the channel. The filter weights are adapted several times per packet according to a performance metric.

3. RESULTS AND DISCUSSION

The effectiveness of turbo multiuser techniques is demonstrated using data transmitted on three shallow water channels. The data were collected from sea trials carried out by the Newcastle University, in the North Sea. The choice of the simulation parameters for each channel is valid for all packets since experimental data demonstrate similar properties. For more information on this, see the experimental setup in [4]. In these experiments and with $K=3$, the DFE-based CDMA receivers produced no errors over 15 transmitted packets except for 2 bits over 500 trials with long code CDMA, whereas the BERs of the receivers based on Rake in Table 1 and Fig.2 increase significantly. However, the Rake receiver demonstrates expectable performance for some of these trials.
Table 1: Performance results of different CDMA receivers.

<table>
<thead>
<tr>
<th>Channel Range (m)</th>
<th>200</th>
<th>500</th>
<th>1000</th>
<th>200</th>
<th>500</th>
<th>1000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average BER</td>
<td>1681/46080</td>
<td>84/46080</td>
<td>359/46080</td>
<td>0</td>
<td>2/46080</td>
<td>0</td>
</tr>
<tr>
<td>Average SINR (dB)</td>
<td>6.3</td>
<td>9.8</td>
<td>9.3</td>
<td>10.3</td>
<td>10.4</td>
<td>11</td>
</tr>
</tbody>
</table>

The performance of the Rake CDMA receivers is affected by channel estimation errors. In the case of high variation of the transmission channel as in the 200 m channel range, the performance of various receivers is deteriorated since the equalization is not perfect in a time-varying fading environment. However, the degradation in performance due to channel estimation is not severe. Further, it is not surprising to see that both forms of direct CDMA receiver have much better performance and are less affected and limited by other factors, such as ISI. The results in terms of signal-to-interference and noise ratio (SINR) are also shown in Fig.3 and illustrate this deterioration for the rake receivers, where the channel estimation errors increase with increasing channel variation. The direct adaptive equalizer also suffers minor deterioration with increasing channel delay spread. The reason is that adaptive equalization becomes difficult to mitigate ISI and trace the variation of the transmission channel. However, the direct adaptive receivers generally outperform the Rake receiver.

Fig.2: BER performance of Rake CDMA receivers.
4. CONCLUSIONS

Turbo CDMA with effective direct form equalization and decoding receivers were presented as an efficient alternative to the joint detection methods for Rake CDMA receivers based channel estimation. The robustness to interference of systems in chip synchronous situations was evaluated for different channels ranges. The algorithms based on continuous pilots adapt the tap coefficients at chip rate; therefore, it is capable of tracking the changes in underwater channels. Furthermore, by including multiuser detection implemented by PIC, MAI can be suppressed effectively. Finally, the results show significant performance improvements when direct adaptive forms of CDMA are employed instead of the conventional receiver in both downlink forms of CDMA.

5. REFERENCES