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Overview

Block spread CDMA (BS-CDMA) [1] is a multi-access technique whereby user-specific spreading along with orthogonal spreading codes are used to achieve multiuser interference (MUI) free reception when signals of all users arrive at the base station synchronously.

In practice however, imperfect synchronization destroys the orthogonality among users and MUI occurs. This paper investigates the design of linear frequency domain equalizers to reduce the MUI for a quasi-synchronous BS-CDMA system. An optimal frequency domain linear minimum-mean square error (MMSE) equalizer is derived. Further simplification leads to a novel sub-optimal equalizer with reduced computational complexity. It is shown through simulation that the proposed equalizers effectively suppress the error floor due to quasi-synchronous reception when channel coding is used.

Quasi-synchronous reception

Quasi-synchronous reception assumption: The timing control at the base station is good enough such that signals from different users are approximately synchronized to within a few chips.

Interference users can be categorized into:
- Users whose signals arrive chips after the synchronization instant
- Users whose signals arrive chips before the synchronization instant

Received signal after despreading

\[ r_i = s_i + b_i(H^H \sum_{j=1}^{K} A_i A_j^H s_j) + b_i(H^H \sum_{j=1}^{K} A_i A_j^H s_j) \]

where
- \( C_{i} \) is a circulant matrix obtained by circularly shifting the identity matrix down by \( j \) entries.
- \( \mathbf{A}_{k} \) and \( \mathbf{A}_{k}^\prime \) are upper and lower triangular matrices with structures

The triangular areas contain the only non-zero entries in the matrices.
- \( k \) and \( \bar{k} \) are the number of users whose signals arrive after and before the synchronization instant

Important observations

- Interfering signals arriving after the synchronization instant are caused by the last \( 1-\bar{k} \) chips of channel taps.
- Interfering signals arriving before the synchronization instant are caused by the first \( k \) channel taps.

For practical channels such as the exponential decay channel, the energy of the first few taps dominates. Users whose signals arrive earlier than the synchronization instant contribute majority of the interference power.

Novel Frequency Domain Equalizers

Optimal LMMSE Equalizer

Objective: to minimize the mean square error (MSE) between the transmitted and recovered signal, given by

\[ e = \text{Tr} [ (w_a - w_b) w_d ] \]

where \( w_a \) is the data block after equalization.

- Obtained by solving \( C_{1}^\prime \) \( \bar{C}_{1}^\prime \) \( \bar{G}_{1} \) \( \bar{G}_{1} \) = \( \bar{G}_{1} \)

Calculation of the optimal LMMSE equalizer requires matrix inverse — high computational complexity!

Suboptimal Equalizer

Objective: To reduce the computational complexity of the optimal LMMSE equalizer
- Obtained by taking expectation over the channel taps as well
- Can be computed recursively by using the matrix inverse lemma

Matrix inverse lemma:

If a matrix is defined as: \( \mathbf{C} = \mathbf{A} \times \mathbf{x} \)
Then its inverse can be computed as: \( \mathbf{C}^{-1} = \mathbf{A} \times \mathbf{x} \times \mathbf{A} \times \mathbf{x} \)

Effects of system parameters on the performance of BS-CDMA:

Observations:
- Systems using the proposed optimal and sub-optimal LMMSE equalizers achieve very close performance
- Compared to the BER of a system using the conventional LMMSE equalizer, systems using the proposed equalizers provide improved performance
- Performance of systems with quasi-synchronous reception degrades with longer delays or larger number of users

Performance for uncoded and coded BS-CDMA:

- 8 active users
- The only asynchronous user has a delay of \( \tau \)
- Convolutional codes with constraint length 7 and code rate 1/2 for the coded systems

References