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A General Framework for Designing Sparse FIR MIMO Equalizers Based on Sparse Approximation

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In broadband communications, the long channel delay spread, defined as the duration in time, or samples, over which the channel impulse response (CIR) has significant energy, is too long and results in a highly-frequency-selective channel frequency response. Hence, a long CIR can spread over tens, or even hundreds, of symbol periods and causes impairments in the signals that have passed through such channels. For instance, a large delay spread causes inter-symbol interference (ISI) and inter-carrier interference (ICI) in multi-carrier modulation (MCM). Therefore, long finite impulse response (FIR) equalizers have to be implemented at high sampling rates to avoid performance degradation. However, the implementation of such equalizers is prohibitively expensive as the design complexity of FIR equalizers grows proportional to the square of the number of nonzero taps in the filter. Sparse equalization, where only few nonzero coefficients are employed, is a widely-used technique to reduce complexity at the cost of a tolerable performance loss. Nevertheless, reliably determining the locations of these nonzero coefficients is often very challenging.

In this work, we first propose a general framework that transforms the problem of design of sparse single-input single-output (SISO) and multiple-input multiple-output (MIMO) linear equalizers (LEs) into the problem of sparsest-approximation of a vector in different dictionaries. In addition, we compare several choices of sparsifying dictionaries under this framework. Furthermore, the worst-case coherence of these dictionaries, which determines their sparsifying effectiveness, are analytically and/or numerically evaluated. Second, we extend our framework to accommodate SISO and MIMO non-linear decision-feedback equalizers (DFEs). Similar to the sparse FIR LEs design problem, the design of sparse FIR DFEs can be cast into one of sparse approximation of a vector by a fixed dictionary

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whose solution can be obtained by using either greedy algorithms, such as Orthogonal Matching Pursuit (OMP), or convex-optimization-based approaches, with the former being more desirable due to its low complexity. Third, we further generalize our sparse design framework to the channel shortening setup. Channel shortening equalizers (CSEs) are used to ensure that the cascade of a long CIR and the CSE is approximately equivalent to a target impulse response (TIR) with much shorter delay spread. Channel shortening is essential for communication systems operating over highly-dispersive broadband channels with large channel delay spread. Fourth, as an application of recent practical interest for power-line communication (PLC) community, we consider channel shortening for the impulse responses of medium-voltage power-lines (MV-PLs) with length of 10 km and 20 km to reduce the cyclic prefix (CP) overhead in orthogonal frequency-division multiplexing (OFDM) and, hence, improves the data rate accordingly. For all design problems, we propose reduced-complexity sparse FIR SISO and MIMO linear and non-linear equalizers by exploiting the asymptotic equivalence of Toeplitz and circulant matrices, where the matrix factorizations involved in our design analysis can be carried out efficiently using the fast Fourier transform (FFT) and inverse FFT with negligible performance loss as the number of filter taps increases.

Finally, the simulation results show that allowing for a little performance loss yields a significant reduction in the number of active filter taps, for all proposed LEs and DFEs design filters, which in turn results in substantial complexity reductions. The simulation results also show that the CIRs of MV-PLs with length of 10 km and 20 km can be shortened to fit within the broadband PLC standards. Additionally, our simulations validate that the sparsifying dictionary with the smallest worst-case coherence results in the sparsest FIR filter design. Furthermore, the numerical results demonstrate the superiority of our proposed approach compared to conventional sparse FIR filters in terms of both performance and computational complexity.

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