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A Novel Frequency-Domain Implementation of Tomlinson-Harashima Precoding for SC-FDMA

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Single Carrier Frequency Division Multiple Access (SC-FDMA) is the uplink transmission scheme in the 3GPP LTE standard. SC-FDMA can be used with a range of single carrier equalization techniques to combat ISI. In fact a common assumption in SC-FDMA is to use Linear and Decision Feedback Frequency-Domain Equalization (FDE). We propose the frequency-domain implementation of Tomlinson-Harashima Precoding (THP) for uplink SC-FDMA, as an alternative signal processing technique to equalization, in order to achieve an ISI-free signal at the receiver by performing ISI cancellation prior to transmission.

Why SC-FDMA?
- OFDMA is not well-suited to the uplink transmission in the 3GPP LTE as a result of its high PAPR.
- SC-FDMA, also known as the DFT precoded OFDMA, has been proposed in the LTE standard for the uplink instead.
- SC-FDMA is also regarded as a form of SC-FDE with a flexibility in resource allocation.

Performance of SC-FDMA with FDE:
- FDE is a very attractive signal processing technique to deal with large time dispersive multipath channels, and can be implemented in the form of an FD-LE or an FD-DFE.
- Although FD-DFE offers a performance that is superior to FD-LE, it suffers from a performance degradation as a result of error propagation, especially for long delay spread channels and coded systems.

Tomlinson-Harashima Precoding:
- THP tackles the error propagation problem in a DFE and offers a further improvement when coding is applied.
- THP combats ISI transmissions, and achieves transmission at the full channel capacity.

Conclusions:
- THP achieves the ideal-DFE performance for coded and uncoded systems.
  - Precoding requires perfect knowledge of the uplink channel at the transmitter.
- Because the PAPR of the precoder’s output is dependent on the channel fading, it is essential to employ some form of PAPR reduction.

TD Tomlinson-Harashima Precoding for SC-FDMA:
- The time-domain operation of THP is connected to the signal constellation, SC-FDMA, however, does not have a distinct constellation.
- The precoder’s input is the SC-FDMA signal after CP insertion transforms the linear convolution into cyclical convolution.
- By rearranging the previous equation and taking the N-point DFT:

  \[ X_k = \left( 1 + \sum_{n=0}^{L-1} b_n e^{-j2\pi \frac{k}{L}} \right) Y_k = B_kY_k \]

- The T-domain implementation of THP is a realizable and effective implementation, especially as the channel delay spread increases.
- The THP coefficients can be designed according to the ZF or MMSE criterion.