Delay Diversity Methods for Parallel OFDM Relays

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INTRODUCTION

Relays form a distributed antenna system that can be used for extending the coverage of wireless OFDM networks in a cost-efficient manner. We consider a general network where N_r parallel relay nodes (RNs) amplify and forward signals from a base station (BS). Multipath fading is beneficial for OFDM transmission as it increases frequency selectivity which can be exploited by forward error control coding. When relays apply linear or cyclic delay diversity methods [1] to create longer multipath channels, dependence on the propagation environment is reduced. In this paper, we summarize relaying protocols and explain how they facilitate the delay diversity methods. We aim at providing maximum diversity gain, but how it translates to performance gain depends on used coding scheme.

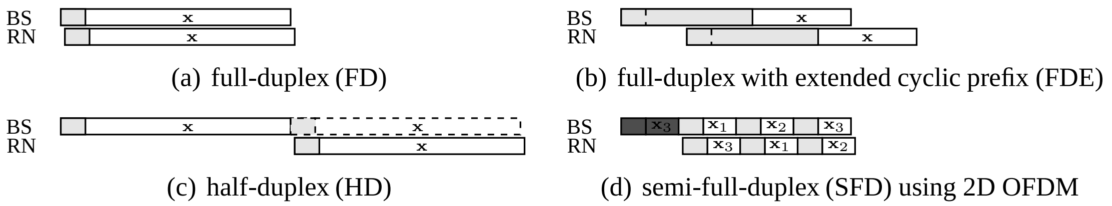
RELAYING PROTOCOLS

In the following, N_tot denotes the total number of samples in each OFDM symbol that consists of subcarriers and N_CP samples of the OFDM cyclic prefix (CP).

In full-duplex (FD) relaying, the BS and RNs transmit the same 1D OFDM symbol simultaneously, and the rate is thus $\mathcal{R}_\mathrm{FD} = 1 - N_\mathrm{CP}/N_\mathrm{tot}$. If the relays introduce any extra delay, the CP has to be extended. In FD relaying with extended CP (FDE), we define the CP extension for fair diversity comparison in such a way that the rate equals to half-duplex relaying rate ($\mathcal{R}_\mathrm{FDE} = \mathcal{R}_\mathrm{HD}$). Thus, the length of the extended CP becomes $\hat{N}_\mathrm{CP} = (N_\mathrm{tot} + N_\mathrm{CP})/2$.

Half-duplex (HD) relaying consists of alternating transmissions of the BS and the RNs with two orthogonal time slots. Thus, the rate is $\mathcal{R}_\mathrm{HD} = \mathcal{R}_\mathrm{FD}/2$.

Semi-full-duplex (SFD) relaying exploits 2D OFDM [2], which allows BS and RNs to transmit simultaneously different consecutive 1D sub-symbols without inter-symbol interference. The SFD protocol achieves the rate $\mathcal{R}_\mathrm{SFD} = MN/N_\mathrm{tot}$, which depends on the selection of the 2D OFDM symbol dimensions M and N. Selecting the optimal symbol dimensions [2], the maximized rate becomes $\mathcal{R}^*_\mathrm{SFD} = (1 - \sqrt{N_\mathrm{CP}/N_\mathrm{tot}})^2$.



(a) full-duplex (FD)

(b) full-duplex with extended cyclic prefix (FDE)

(c) half-duplex (HD)

(d) semi-full-duplex (SFD) using 2D OFDM

Figure 1: Superposition of symbols as received by a mobile terminal.

DELAY DIVERSITY METHODS

Linear delay diversity (DD) makes the effective channel longer and more frequency selective. The BS and the RNs are spatially dislocated, which causes spreading in the arrival times of signals. This inherent delay diversity (IDD) arises with every relaying protocol by merely adding relays to a system. Unfortunately, IDD gains depend significantly on the transceiver locations and cannot be controlled by tuning transmission parameters at the RNs. Artificial linear delay diversity can be implemented by using the FDE protocol. The extended CP allows RNs to apply extra transmission delays without creating inter-carrier interference, but this results in rate decrease.

In cyclic delay diversity (CDD), the relays cyclically shift the time domain 1D symbols before adding the CP. Cyclic shift creates virtually longer channel impulse response without requiring longer CP. The relays have to receive the whole 1D symbol to be able to perform the cyclic shift. Thus, full-duplex relaying is not possible with CDD. Half-duplex relaying is the most intuitive method to facilitate CDD. An improved method to allow for CDD is semi-full-duplex relaying, because then a RN can transmit a cyclically shifted version of a 1D sub-symbol. The destination receives a sum of two different 1D sub-symbols, but the 2D symbol structure guarantees interference-free transmission.

DISCUSSION

The 2D OFDM allows SFD protocol which increases the rate, but at the same time additional overhead is created. A rate increase is achieved by CDD-SFD relaying compared to CDD-HD relaying when $N_{\mathrm{CP}} < N_{\mathrm{tot}}/9$ [2]. For example, in the DVB-T/H standard $N_{\mathrm{CP}}/N_{\mathrm{tot}}$ takes the values $1/5$, $1/9$, $1/17$ or $1/33$ for which the rate gain of SFD relaying over HD (and also FDE) relaying is -23.6%, 0%, 21.9%, or 40.7%, respectively.

The delay shifts employed by the relays should be selected with adequate spacing to get full diversity benefits, which limits the number of relays, N_{r}. To achieve maximum delay diversity, the effective channel taps at the destination should be uncorrelated. Thus, transmissions from BS and RNs should be delayed at least by the length of the channel impulse response. In general, exact length of the channel impulse response is not known, but a safe choice to guarantee maximum diversity is to use delay difference of N_{CP} samples.

In DD, the number of possible choices for delay shifts is limited by the length of the extended CP. Therefore, the number of relays in the network with full diversity is $N_{\mathrm{r}} \leq (N_{\mathrm{tot}}/N_{\mathrm{CP}} - 1)/2$ for DD-FDE. On the other hand, in CDD the number of possible delay shifts is limited by the length of the 1D OFDM symbol payload. Therefore, to get full diversity, the number of relays is limited by $N_{\mathrm{r}} \leq N_{\mathrm{tot}}/N_{\mathrm{CP}} - 1$ with CDD-HD. With CDD-SFD using rate maximizing symbol dimensions [2], the number of relays is limited by $N_{\mathrm{r}} \leq \sqrt{N_{\mathrm{tot}}/N_{\mathrm{CP}}} - 1$ when full diversity is preferred. Thus, CDD-SFD can support less relays, but gives significant rate gain, if the CP is short enough.

REFERENCES

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