Delay Diversity Methods for Parallel OFDM Relays

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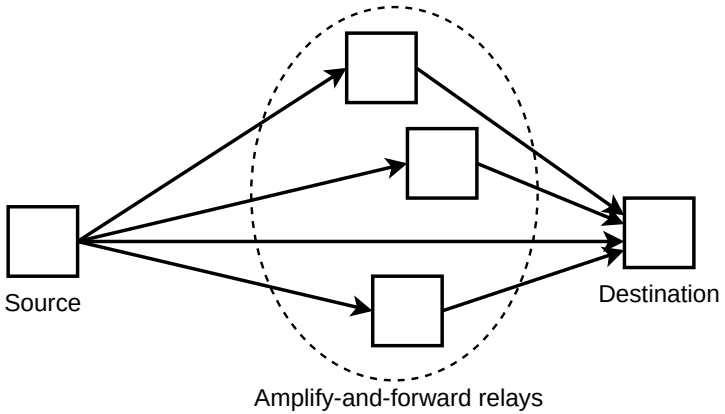
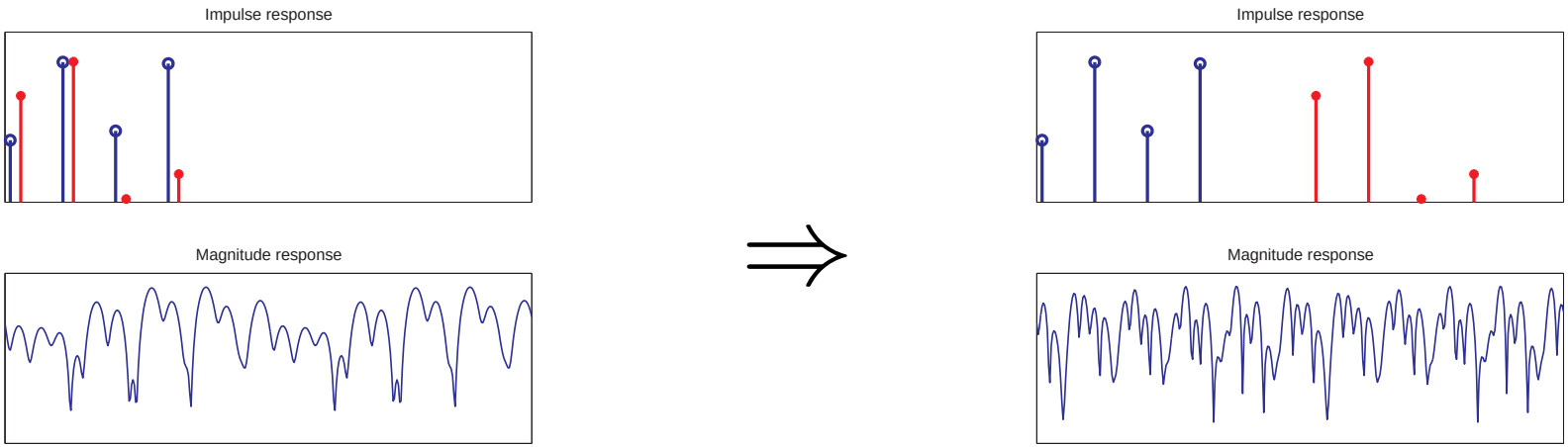
Parallel relay link



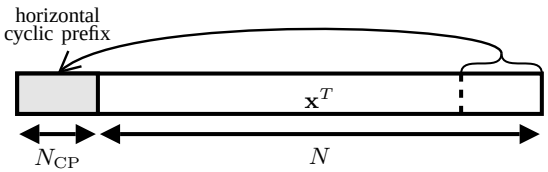
- N_r parallel relay nodes (RNs) amplify and forward OFDM signals from a base station (BS) to a mobile user equipment (UE)
- A distributed antenna system is formed
  - Coverage extension without increasing transmit powers
  - Hotspot capacity enhancement in a cost-efficient manner

Frequency selectivity vs. delay diversity

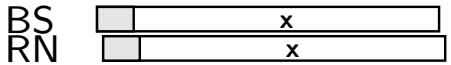


- Multipath fading is beneficial for OFDM transmission, because it increases frequency selectivity which can be exploited by forward error control coding
  - When relays apply linear or cyclic delay diversity dependence on the propagation environment is reduced
- In this presentation, we summarize relaying protocols and explain how they facilitate the delay diversity methods

Full-duplex (FD)

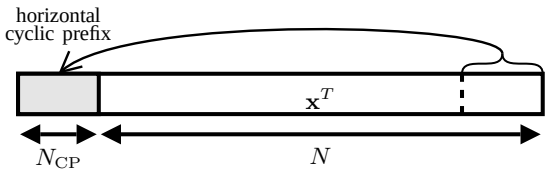


- Conventional (1D) OFDM:
- The BS and RNs transmit the same 1D OFDM symbol simultaneously, and the rate is thus $\mathcal{R}_{\mathrm{FD}} = 1 - N_{\mathrm{CP}}/N_{\mathrm{tot}}$

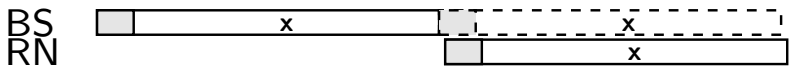


  - If the relays introduce any extra delay, the CP has to be extended
- In FD relaying with extended CP (FDE), the CP extension is defined in such a way that the rate equals to half-duplex relaying rate ($\mathcal{R}_{\mathrm{FDE}} = \mathcal{R}_{\mathrm{HD}}$)
  - The length of the extended CP becomes $\hat{N}_{\mathrm{CP}} = (N_{\mathrm{tot}} + N_{\mathrm{CP}})/2$

Half-duplex (HD)



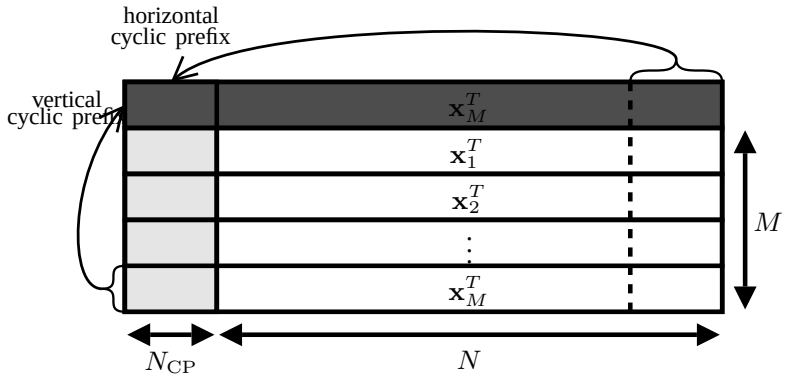
- Also conventional (1D) OFDM:
- Alternating transmissions of the BS and the RNs with two orthogonal time slots



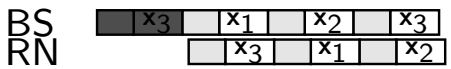
  - Possibility for BS repetition during the second slot
  - Rate is $\mathcal{R}_{\mathrm{HD}} = \mathcal{R}_{\mathrm{FD}}/2$

Semi-full-duplex (SFD)

- New 2D OFDM symbol structure for relay links:



- BS and RNs can 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 2D OFDM symbol dimensions M and N
  - Selecting the optimal symbol dimensions, the maximized rate becomes $\mathcal{R}^*_{\mathrm{SFD}} = (1 - \sqrt{N_{\mathrm{CP}}/N_{\mathrm{tot}}})^2$

Linear delay diversity (DD)

- The effective channel becomes longer and more frequency selective
- The BS and the RNs are spatially dislocated, which causes spreading in the arrival times of signals
  - Inherent delay diversity (IDD) by merely adding relays to the system
  - IDD gains depend significantly on the transceiver locations and cannot be controlled by tuning transmission parameters at the RNs
- Additional linear delay diversity by using the FDE protocol
  - The extended CP allows RNs to apply extra delays without creating inter-carrier interference, but this results in rate decrease

Cyclic delay diversity (CDD)

- Relays cyclically shift the 1D symbols before adding the cyclic prefix
  - Virtually longer channel impulse response is created without requiring longer CP
- The relays have to receive the whole 1D symbol to be able to perform the cyclic shift
  - 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

Comparison

- 2D OFDM increases the rate, but creates some overhead
  - A rate increase is achieved by CDD-SFD relaying compared to CDD-HD relaying when $N_{\mathrm{CP}} < N_{\mathrm{tot}}/9$
- 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}
  - In DD, the number of shifts is limited by the extended CP
    - With full diversity $N_{\mathrm{r}} \leq (N_{\mathrm{tot}}/N_{\mathrm{CP}} - 1)/2$ for DD-FDE
  - In CDD, the number of shifts is limited by the 1D symbol payload
    - With full diversity $N_{\mathrm{r}} \leq N_{\mathrm{tot}}/N_{\mathrm{CP}} - 1$ for CDD-HD
    - With full diversity $N_{\mathrm{r}} \leq \sqrt{N_{\mathrm{tot}}/N_{\mathrm{CP}}} - 1$ for CDD-SFD
- CDD-SFD can support less relays, but may provide rate improvement

TABLE I
MAXIMUM RATE IMPROMENT OF SEMI-FULL-DUPLEX OVER HALF-DUPLEX IN DVB-T/H

$N_{\mathrm{CP}}/N_{\mathrm{tot}}$	$\frac{1}{5}$	$\frac{1}{9}$	$\frac{1}{17}$	$\frac{1}{33}$
$\mathcal{R}^*_{\mathrm{SFD}}/\mathcal{R}_{\mathrm{HD}}$	-23.6%	0%	21.9%	40.7%

TABLE II
MAXIMUM NUMBER OF RELAYS IN A DVB-T/H SYSTEM IF FULL DIVERSITY GAIN IS DESIRED

$\frac{N_{\mathrm{CP}}}{N_{\mathrm{tot}}}$	$\frac{1}{5}$	$\frac{1}{9}$	$\frac{1}{17}$	$\frac{1}{33}$
DD-FDE	2	4	8	16
CDD-HD	4	8	16	32
CDD-SFD	1	2	3	4

Simulation setup

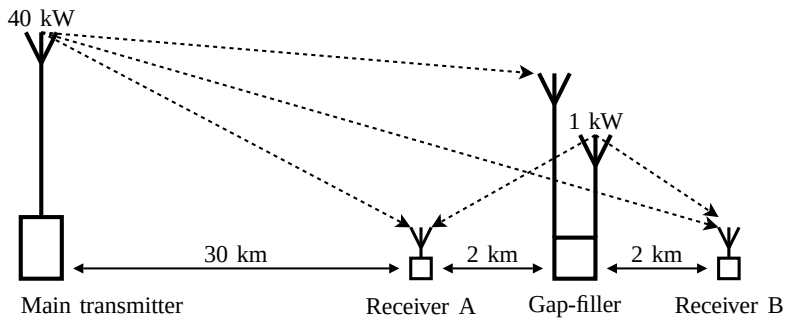


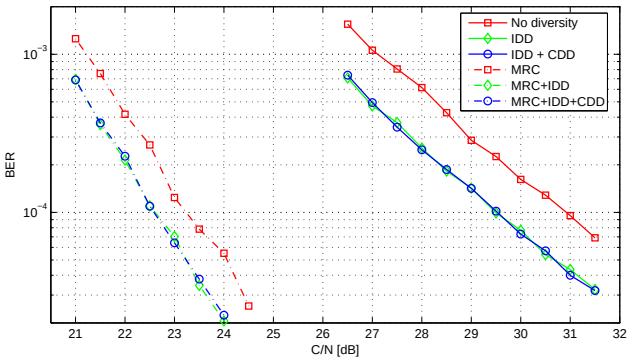
TABLE III
THE SIMULATION PARAMETERS FOR THE DVB-T TRANSMISSION

Parameter	Value
Bandwidth	8 MHz
Sampling Period	7/64 μs
DFT Size	8192
CP Size	1024
Number of Data Subcarriers	6048
Number of Pilot Subcarriers	701
Constellation	64-QAM
Coding Scheme	Punctured convolutional
Coding Rate	2/3
Channel State Information	Ideal
Equalizer	MMSE

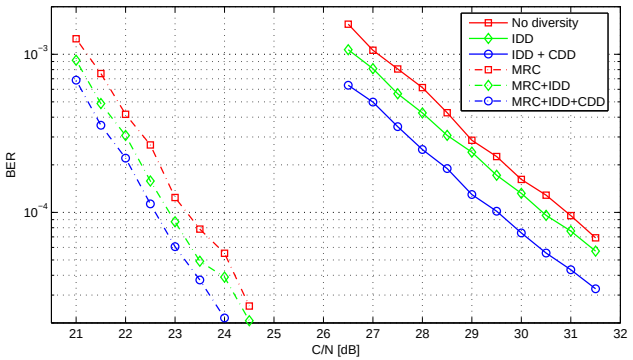
- Bit error rate (BER) simulations in a DVB-T/H type of network
- Study of delay diversity by comparing performance at two receiver locations

Example results

Receiver A:



Receiver B:



- Error performance when only the direct link transmission is received (No diversity) or the network exploits different combinations of Inherent Delay Diversity (IDD), Cyclic Delay Diversity (CDD) in the relay and Maximum Ratio Combining (MRC) at the receiver node
- Additional cyclic delay diversity guarantees SNR gain that does not depend on the receiver location

Conclusion

- Delay diversity and frequency selectivity are beneficial for OFDM
- Selection of relaying protocol determines available delay diversity methods
  - Full-duplex requires extension of cyclic prefix to facilitate linear delay diversity, but no possibility for cyclic delay diversity
  - Semi-full-duplex (2D OFDM) transmission allows cyclic delay diversity with better rate than half-duplex
- By applying delay diversity methods in relays, the diversity gains become more independent of the system geometry

Thank you!

- Questions?
- Discussion?