Amplify Based Double-Differential Modulation for Cooperative Communications

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Review of Previous Work (Among Others)

- Cooperative communication [Laneman et al., 2004], [Sendonaris et al., 2003], [Nosratinia et al., 2004]:
  - Transmit diversity
  - Improve capacity
- Cooperation protocols [Laneman et al.,2004]
  - Decode-and-Forward (DAF)
  - Amplify-and-Forward (AAF)
- Differential modulation for cooperative communications is proposed in [Himsoon et al.,2006] and several others contributions.
- Double-differential (DD) coding for SISO channels [Simon and Divsalar, 1992].
- SER expressions for DD modulation over SISO channels [Bhatnagar and Hjørungnes, 2007].

Contributions

- Double-differential (DD) modulated AAF cooperative wireless communications.
- Analytical SER DDAAF system with one integral.
- Upper bound of SER.
- Power allocation for DDAAF system.

Single Differential Cooperative System

Single Differential Modulation:

- Avoids the transmission of training data for channel estimation.
- Low complexity decoder.

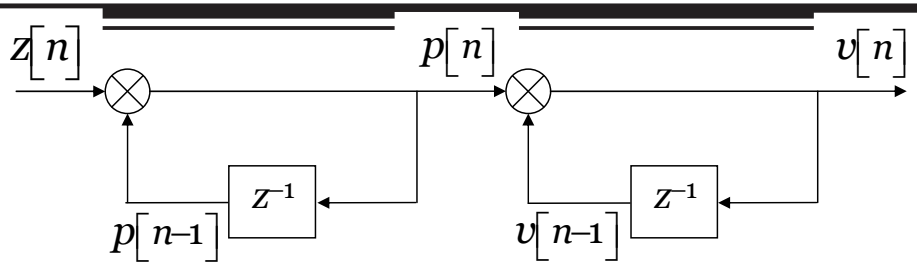
Single Differential Cooperative System:

- Useful for practical implementation.
- Improved data rate.

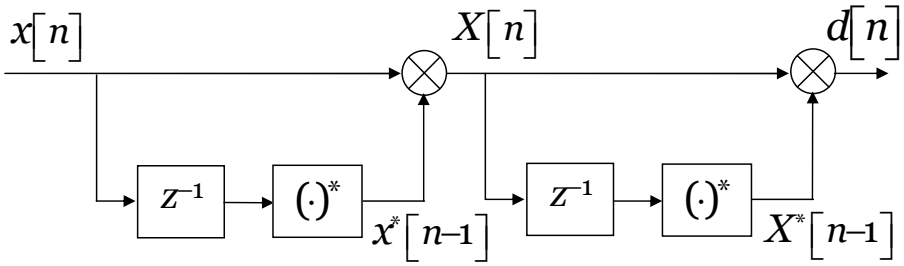
Limitations:

- Channel related.
- Carrier offsets.

Double-Differential Modulation



Double-differential encoder

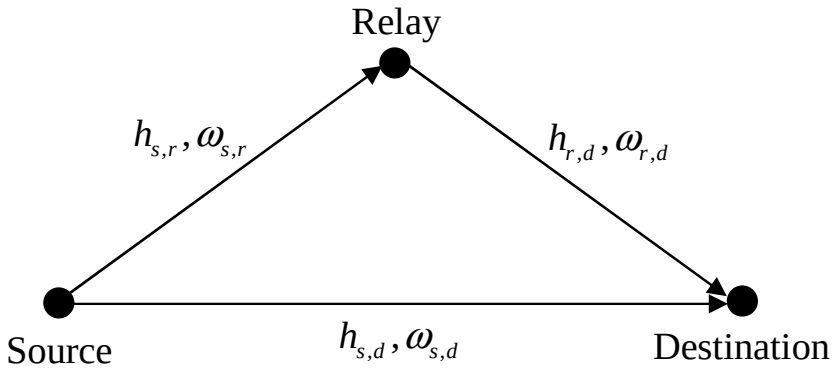


Double-differential decoder

Double-differential (a) encoder and (b) decoder.

- Utilizes two initialization symbols.
- Avoids channel and carrier frequency offset estimation.
- Avoids pilot transmissions.
- Improves data rate.

System Model



- Transmission phases
  - S-D, S-R
  - R-D

- S transmits DD modulated data and R amplifies and forwards the received data to D.

- S and R use orthogonal channels for transmission.

Assumptions Related to The Channel

- Each Rayleigh fading channel remains constant for at least *three* consecutive time intervals.
- Each link has a different random carrier offset $\in [-\pi, \pi>$.
- These offsets are fixed for at least *three* consecutive time-intervals.
- Carrier offset + block fading channel = time-varying channel.

DD Modulation for Cooperative Communications (1/2)

Decision variable for DDDAF cooperative system is formed as

$$d[k] = \alpha_1 (x_{s,d}[n]\, x^*_{s,d}[n-1])(x_{s,d}[n-1]\, x^*_{s,d}[n-2])^* + \alpha_2 (x_{r,d}[l]\, x^*_{r,d}[l-1])(x_{r,d}[l-1]\, x^*_{r,d}[l-2])^*,$$

where $k = n = l$,

$$\alpha_1 = \frac{1}{\left(2P_1 \left|h_{s,d}\right|^2 + \sigma^2\right)\sigma^2},$$

$$\alpha_2 = \frac{\left(P_1 \sigma^2_{s,r} + \sigma^2\right)^2}{\kappa},$$

$$\kappa = 2P_1 P_2^2 \left|h_{r,d}\right|^4 |h_{s,r}|^2 \sigma^2 + 2P_1 P_2 \times \left(P_1 \sigma^2_{s,r} + \sigma^2\right) \left|h_{r,d}\right|^2 |h_{s,r}|^2 \sigma^2 + P_2^2 \left|h_{r,d}\right|^4 \sigma^4 + 2P_2 \times \left(P_1 \sigma^2_{s,r} + \sigma^2\right) \left|h_{r,d}\right|^2 \sigma^4 + \left(P_1 \sigma^2_{s,r} + \sigma^2\right)^2 \sigma^4.$$

DD Modulation for Cooperative Communications (2/2)

- In DD modulation, D and R must work without exact knowledge of the channel gains.
- DD decoder uses variances in place of exact channels.
- Then, the data is decoded as

$$\widehat{z}\left[n\right] = \arg \max_{z \in \Xi} \mathrm{Re}\left\{d\left[k\right] z^{*}\right\},$$

where $n = k$.

SER Performance Analysis

- DD modulation is analogus to SD modulation [Bhatnagar and Hjørungnes, 2007].
- Performance of the DD SISO is obtained from analytical expressions of SD SISO in [Bhatnagar and Hjørungnes, 2007].
- SER expression for DDAAF system with one integral is obtained.
- An upper-bound of SER is also obtained.

Training Based Cooperative System

- Uses two training symbols.
- Carrier offset is estimated as

$$\widehat{\omega} = \arg\{x[1]x^*[0]\}.$$

- Channel is estimated as

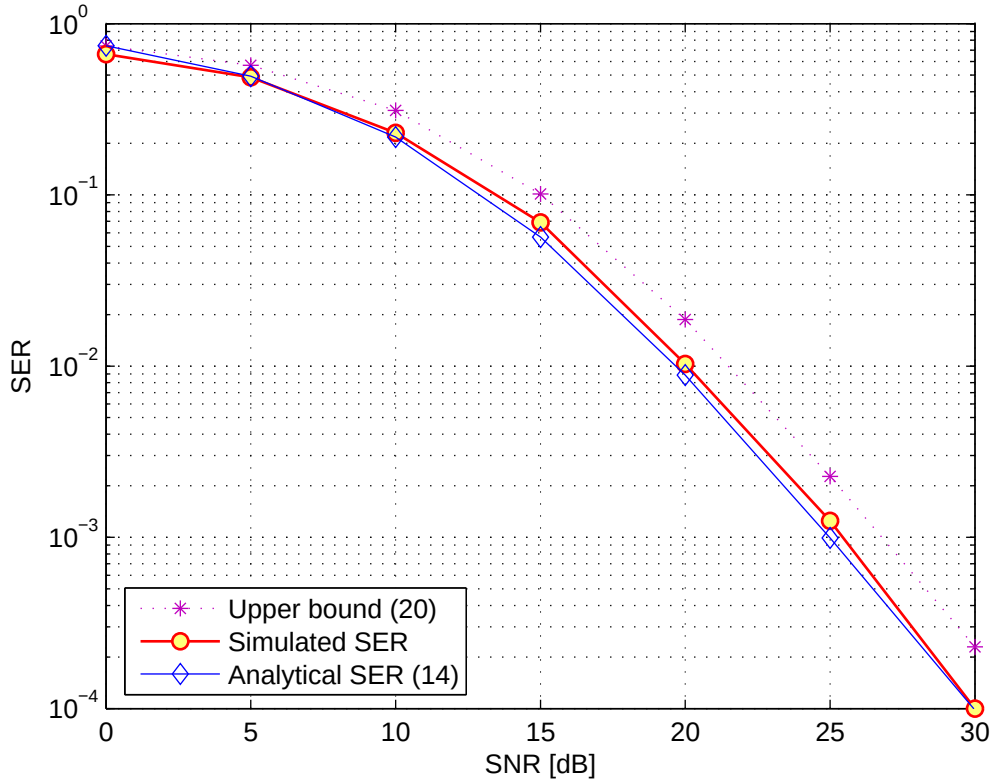
$$\widehat{h} = \frac{1}{2}\left(x[0] + \exp(-\jmath 2\pi\widehat{\omega})x[1]\right).$$

- MRC based decision variable

$$d[k] = \frac{\widehat{h}^*_{s,d}}{\sigma^2}\exp(-\jmath 2\pi\widehat{\omega}_{s,d})y_{s,d}[n] + \frac{\widehat{h}^*_{s,r,d}}{E_N}\exp(-\jmath 2\pi\widehat{\omega}_{s,r,d})y_{r,d}[m],$$

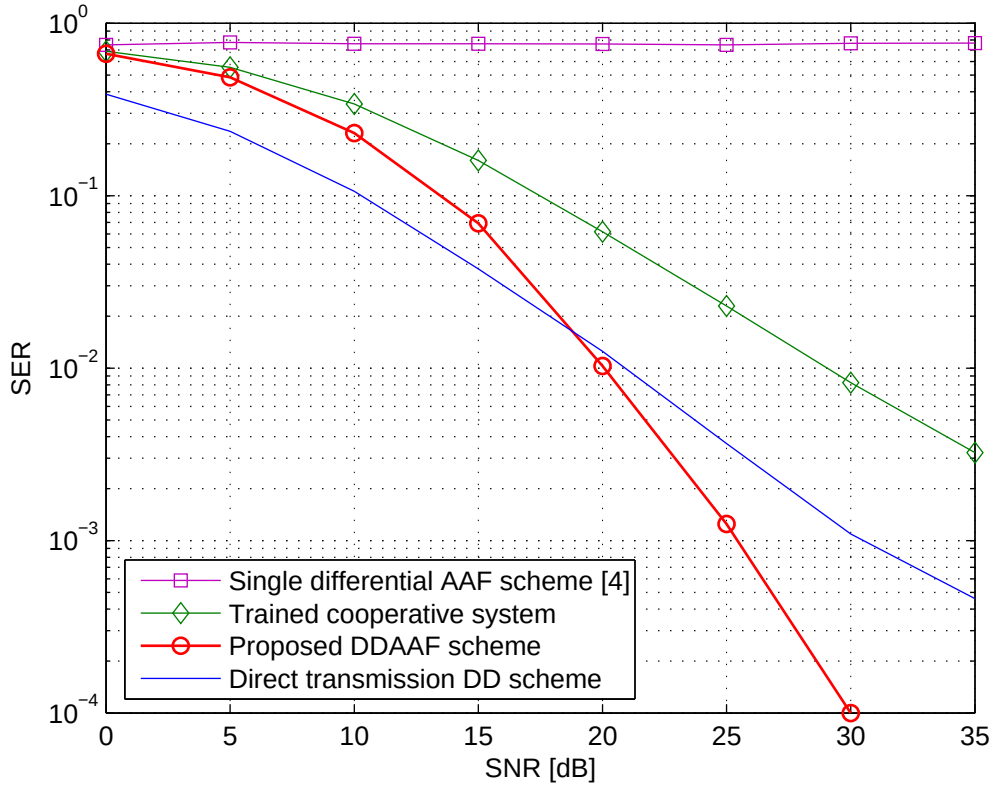
where $k = n = m$ and E_N is the total noise power in $y_{r,d}[m]$.

Performance Evaluation of DDAAF System (1/4)



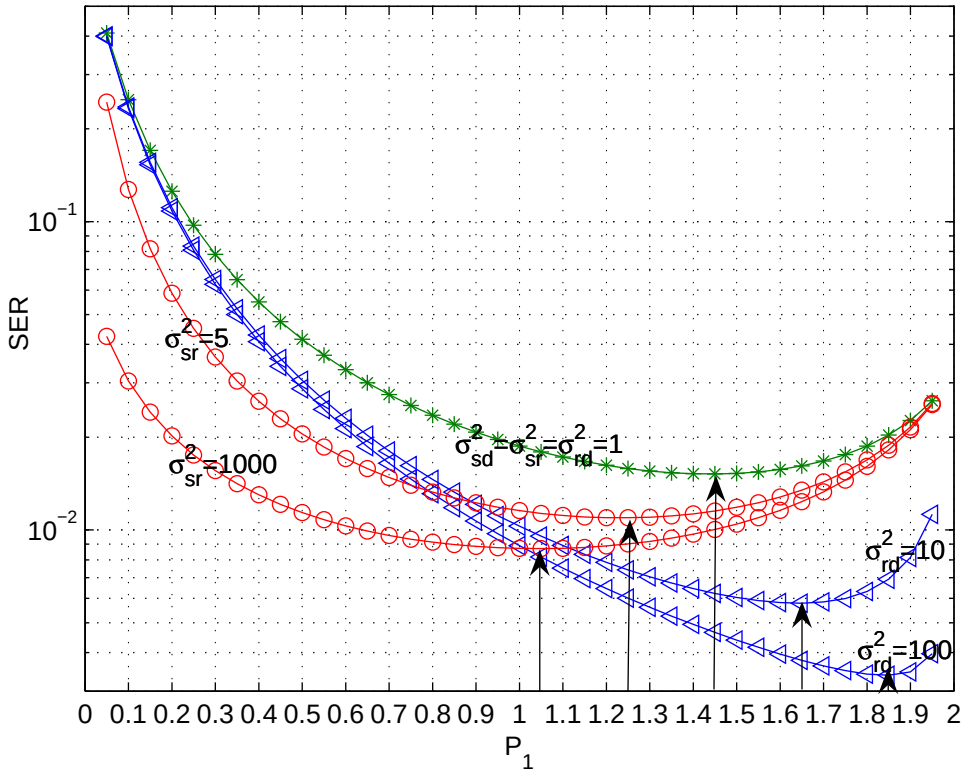
Analytical and experimental performance of DDAAF.

Performance Evaluation of DDAAF System (2/4)



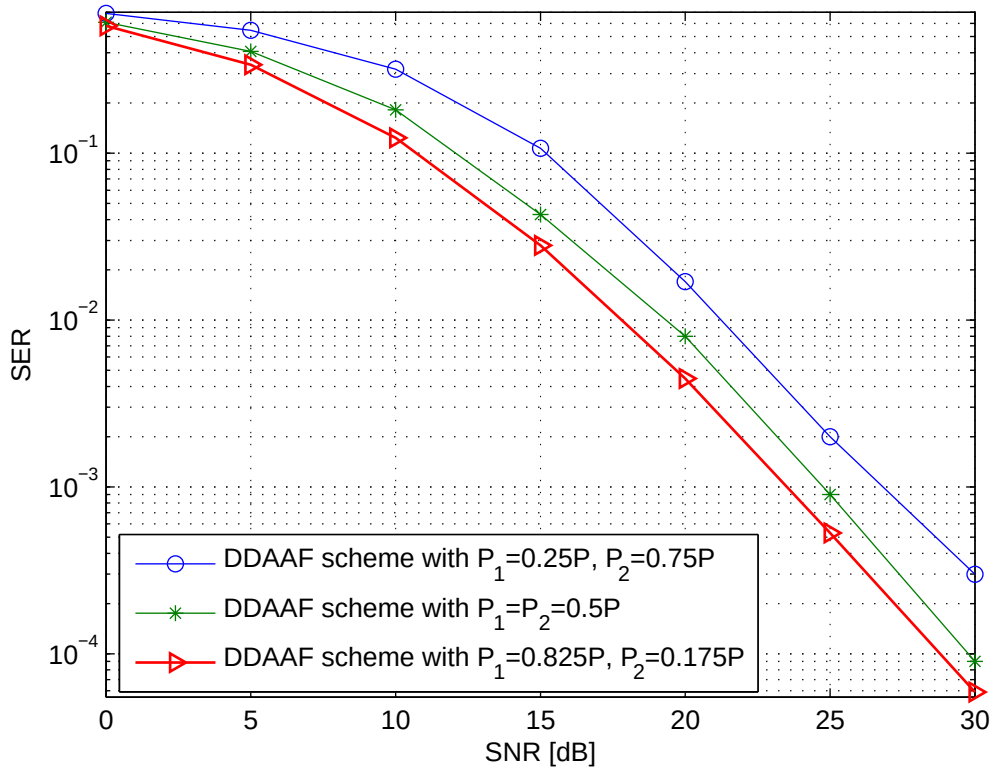
Comparison of DDAAF with trained and SD cooperative systems.

Performance Evaluation of DDAAF System (3/4)



Numerical power distribution, $-\circ-$ for $\sigma^2_{s,d} = \sigma^2_{r,d} = 1$, $-\triangleleft-$ for $\sigma^2_{s,d} = \sigma^2_{s,r} = 1$, and $-*-$ for $\sigma^2_{s,d} = \sigma^2_{s,r} = \sigma^2_{r,d} = 1$.

Performance Evaluation of DDAAF System (4/4)



DDAAF cooperative system with different power distributions and $\sigma^2_{s,r} = 1, \sigma^2_{s,d} = 1$, and $\sigma^2_{r,d} = 10$.

Conclusions

- Proposed DD modulation for cooperative communication.
- DD modulation is more practical than SD modulated cooperation.
- Useful SER expression for DDAAF is derived.
- Implemented training based cooperative system.
- Studied numerical power allocation for DDAAF.

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Thank You!