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Adaptive robust beamformer for multi-pair two-way relay networks with imperfect channel state information

Key words: Multi-pair two-way relay, Adaptive robust beamformer, Channel state information (CSI), Maximum signal-to-interference-and-noise ratio (Max-SINR), Maximum signal-to-leakage-and-noise ratio (Max-SLNR)

Corresponding author: Feng Shu
E-mail: shufeng@njust.edu.cn
ORCID: http://orcid.org/0000-0003-0073-1965

Motivation

- In wideband multi-pair two-way relay networks, the performance of beamforming at a relay station (RS) is intimately related to the accuracy of the channel state information (CSI) available.
- The accuracy of CSI is determined by Doppler spread, delay between beamforming and channel estimation, and density of pilot symbols, including transmit power of pilot symbols.
- Therefore, we develop an adaptive robust Max-SINR plus Max-SLNR beamformer of tracking the channel variation by taking Doppler spread, delay between channel estimation and beamforming, and the density and power of pilot symbols into account.

Paper contribution

- We design the transmit and receive beamforming matrices at the RS by making use of Max-SINR and Max-SLNR criteria in the presence of imperfect CSI.
- The coefficients of the Gaussian-Markov CSI error model are modeled as a function of CSI delay, Doppler spread, and signal-to-noise ratio, and can be estimated in real time.
- In accordance with the real-time estimated coefficients of the error model, an adaptive robust Max-SINR plus maximum Max-SLNR beamformer at an RS is proposed to track the variation of CSI error.

System model

- One central relay station (RS) with *N* antennas
- *K* pairs of mobile stations (MSs) with *M* antennas

$$
\begin{aligned}
\boldsymbol{r}_{k_i}^{uq} = & \beta \left(\boldsymbol{G}_{k_i}^{uq}\right)^{\mathrm{T}} \boldsymbol{W}_{\mathrm{RS}}^{uq} \boldsymbol{H}_{k_{(-i)}}^{uq} \boldsymbol{s}_{k_{(-i)}}^{uq} \\
& + \beta \left(\boldsymbol{G}_{k_i}^{uq}\right)^{\mathrm{T}} \boldsymbol{W}_{\mathrm{RS}}^{uq} \boldsymbol{H}_{k_i}^{uq} \boldsymbol{s}_{k_i}^{uq} + \boldsymbol{c}_{k_i}^{uq} \\
& + \beta \left(\boldsymbol{G}_{k_i}^{uq}\right)^{\mathrm{T}} \boldsymbol{W}_{\mathrm{RS}}^{uq} \boldsymbol{z}_{\mathrm{RS}}^{uq} + \boldsymbol{z}_{k_i}^{uq},
\end{aligned}
$$

CSI error model

$$\widehat{\boldsymbol{H}}_{k_i}^{(u-\Delta u)q} = \rho_{\mathrm{H}} \boldsymbol{H}_{k_i}^{uq} + \sqrt{1-\rho_{\mathrm{H}}^2} \boldsymbol{H}_{\mathrm{e},k_i}^{uq}$$

$$\widehat{\boldsymbol{G}}_{k_i}^{(u-\Delta u)q} = \rho_{\mathrm{G}} \boldsymbol{G}_{k_i}^{uq} + \sqrt{1-\rho_{\mathrm{G}}^2} \boldsymbol{G}_{\mathrm{e},k_i}^{uq},$$

Proposed adaptive robust beamformer

$$\boldsymbol{W}_{\mathrm{RS}}^{uq} = \sum_{k=1}^{K} \sum_{i \in \{a,b\}} \boldsymbol{W}_{\mathrm{t},k_i}^{uq} \left(\boldsymbol{W}_{\mathrm{r},k_{(-i)}}^{uq} \right)^{\mathrm{T}}$$

Max-SLNR

Max-SINR

$$\boldsymbol{B}_{k_i} = \frac{\boldsymbol{\Psi}_1}{\sigma_{\mathrm{RS}}^2 \boldsymbol{I}_N + P_{\mathrm{RS}} N^{-1} \left(\boldsymbol{\Psi}_2 + \boldsymbol{\Psi}_3 \right)}$$

$$\boldsymbol{A}_{k_{(-i)}} = \frac{\boldsymbol{\Phi}_1^{\mathrm{T}}}{\sigma_{\mathrm{RS}}^2 \boldsymbol{I}_N + P_{\mathrm{MS}} M^{-1} \left(\boldsymbol{\Phi}_2 + \boldsymbol{\Phi}_3 \right)^{\mathrm{T}}}$$

Real-time estimation of *ρ*

$$\rho^{u}_{\mathrm{H},k_i} = \rho^{u\mathrm{d}}_{\mathrm{H},k_i}\,\rho^{u\mathrm{e}}_{\mathrm{H},k_i}$$

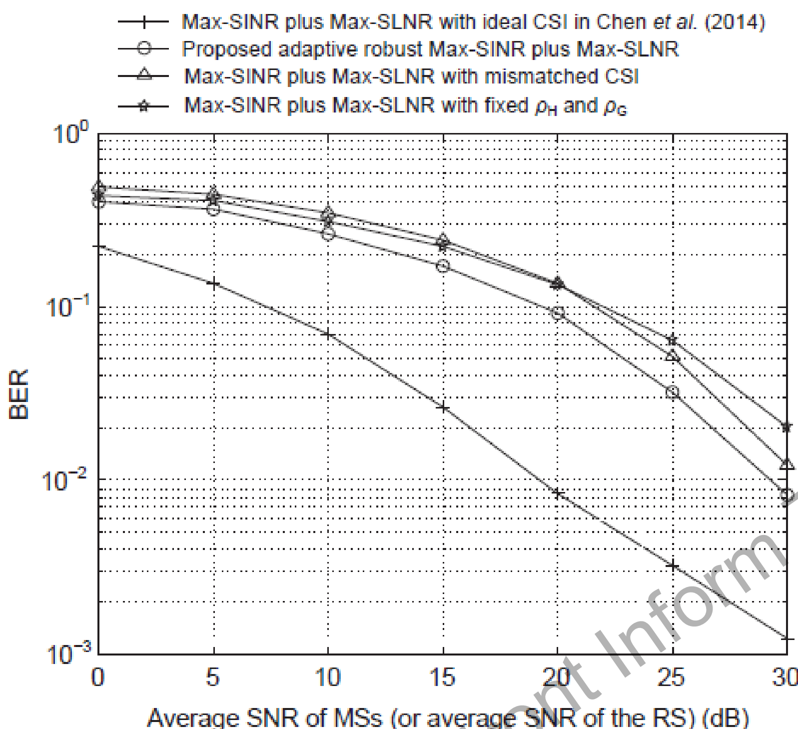
effect of Doppler spread

effect of channel estimation error

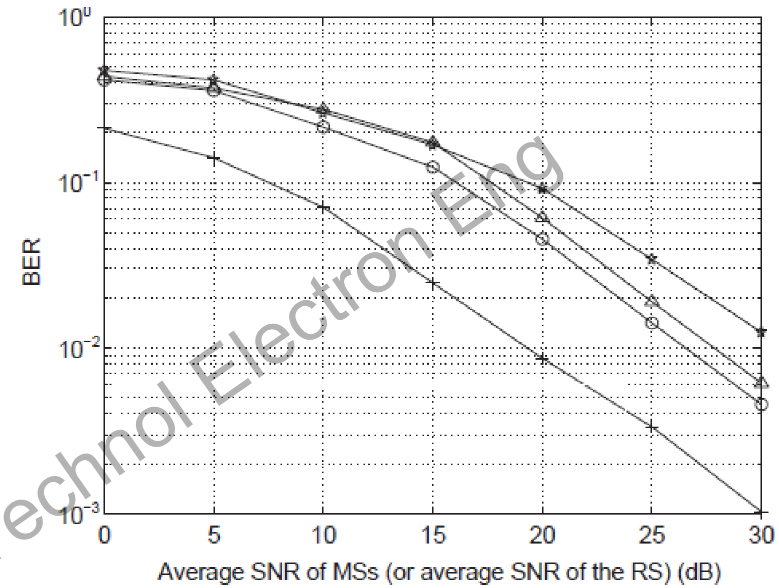
$$\rho^{u\mathrm{d}}_{\mathrm{H},k_i} = \frac{\Re_{\mathrm{HH},k_i}\left(\Delta u, 0\right)}{\Re_{\mathrm{HH},k_i}\left(0, 0\right)}$$

$$\rho^{u\mathrm{e}}_{\mathrm{H},k_i} = \frac{\mathrm{SNR}^{u\mathrm{p}}_{\mathrm{H},k_i}}{1 + \mathrm{SNR}^{u\mathrm{p}}_{\mathrm{H},k_i}}$$

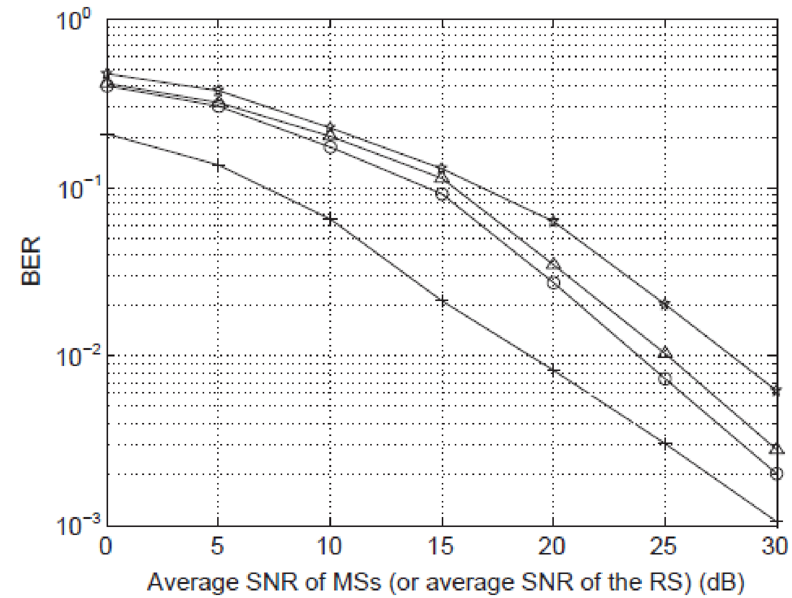
Major results



α=0.5



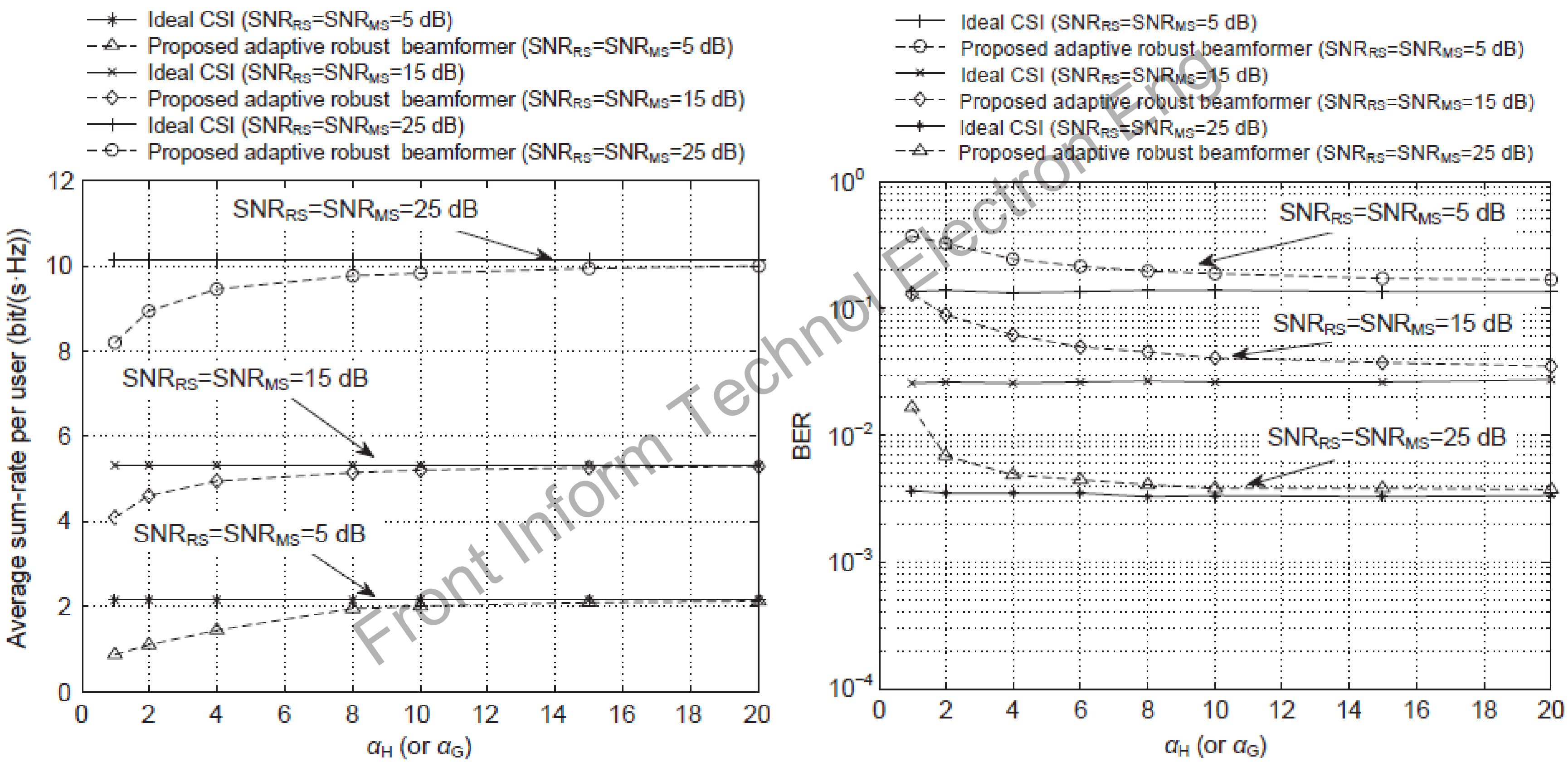
α=1.0



α=2.0

Curves of BER versus SNR of the proposed adaptive robust beamformer and existing non-adaptive ones ($\Delta m f_d T_s$= 0.01)

Major results (Con’d)



Curves of sum-rate and BER versus α of the proposed adaptive robust beamformer at SNR_{RS}=SNR_{MS}=5 dB, 15 dB, 25 dB ($\Delta m f_d T_s$= 0.01)

Conclusions

- By real-time estimation of Doppler spread and SNR in the channel, an adaptive robust Max-SINR plus Max-SLNR beamformer at an RS is proposed to take into account some uncertainty or possible variation in the channel matrix.

- From simulation results and analysis, we find that the proposed robust method can adaptively track channel variation and performs much better than existing robust and non-robust Max-SINR plus Max-SLNR non-adaptive schemes.