Interference-Constrained Cooperative Relaying for Cognitive Radio

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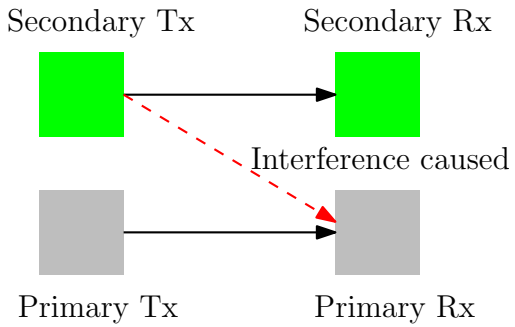
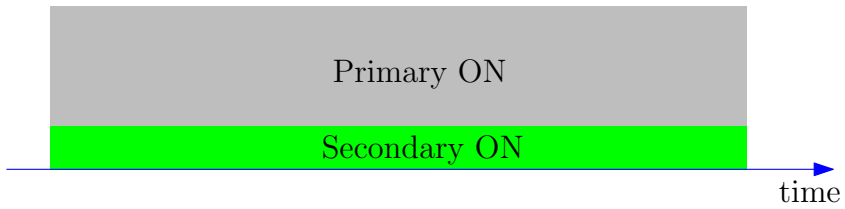
Cognitive Radio (CR)

- CR solves spectrum shortage vs under-utilization dilemma



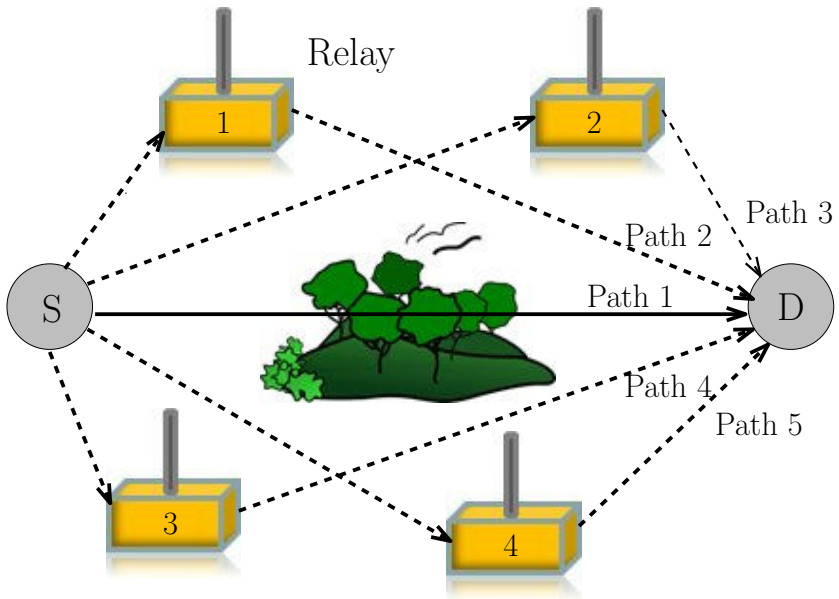
Underlay CR

- Secondary Tx transmits even when primary Tx is ON.
  - Subject to interference constraint to primary Rx.



Interference constraint limits secondary system performance

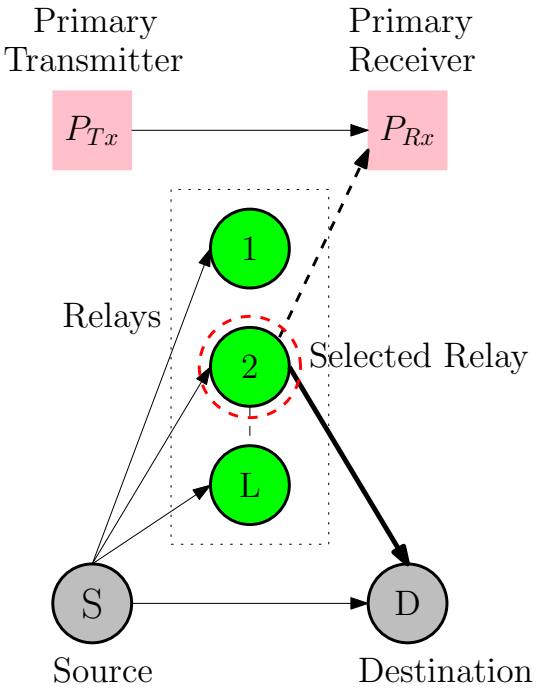
Cooperative Relays in Underlay CR



- Intermediate relay cooperates to forward data
- Provides spatial diversity
  - Increases reliability of transmission

Relaying mitigates effects of interference constraint in underlay CR

Relay Selection in Underlay CR



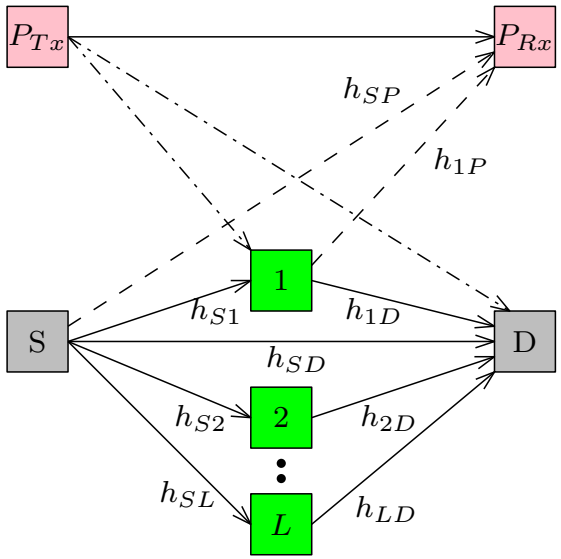
- Best relay selection solves synchronization issue among relays and is spectrally efficient
- Focus: Whether to use relay or not. If yes, which relay?
  - Depends on performance metric considered
    - Reliability (symbol error probability)
    - Rate of communication
  - Interference caused to P_{Rx} by selected relay

Best relay or no relay should be selected to get maximum benefit

System Model and Problem Statement

- Channel model: $y = hx + n$
- Each node has one antenna

- Goal: Find optimal relay selection rule ϕ^*
  - Maximize average rate of transmission
  - or Minimize average SEP
  - Average interference by relay $\leq$ threshold (I_{avg})



Rate Optimization Problem:

$$\max_{\phi} \quad \mathbb{E}_{h_{SD},\mathbf{h}}\left[C\left(\gamma_{SD}, \gamma_{S\beta}, \gamma_{\beta D}\right)\right]$$

$$\text{s.t.} \quad \mathbb{E}_{h_{SD},\mathbf{h}}\left[P_\beta |h_{\beta P}|^2\right] \leq I_{\text{avg}}$$

$$\beta = \phi(h_{SD}, \mathbf{h}) \in \{0, 1, \ldots, L\}$$

Result: Rate-Optimal Relay Selection Rule

- I_{un}: Average interference by relay to P_{Rx} when system is unconstrained

Theorem

The rate-optimal relay β^* *is*

$$\beta^* = \begin{cases} \text{argmax}_{i\in\{0,1,\ldots,L\}} \left\{ C\left(\gamma_{SD}, \gamma_{Si}, \gamma_{iD}\right)\right\}, & I_{un} \leq I_{avg} \\ \text{argmax}_{i\in\{0,1,\ldots,L\}} \left\{ C\left(\gamma_{SD}, \gamma_{Si}, \gamma_{iD}\right) - \lambda P_i |h_{iP}|^2 \right\}, & I_{un} > I_{avg} \end{cases}$$

- $\lambda > 0$ *is chosen s.t.* $\mathbb{E}_{h_{SD},\mathbf{h}}\left[P_{\beta^*}|h_{\beta^* P_{Rx}}|^2\right] = I_{avg}$

Comments:

- Decides which relay or only S-to-D (SD) link should be selected
- Selection policy depends on interference link and SD link states

Our Contributions

- Focused on average interference-constrained underlay CR system
- Optimization objective:

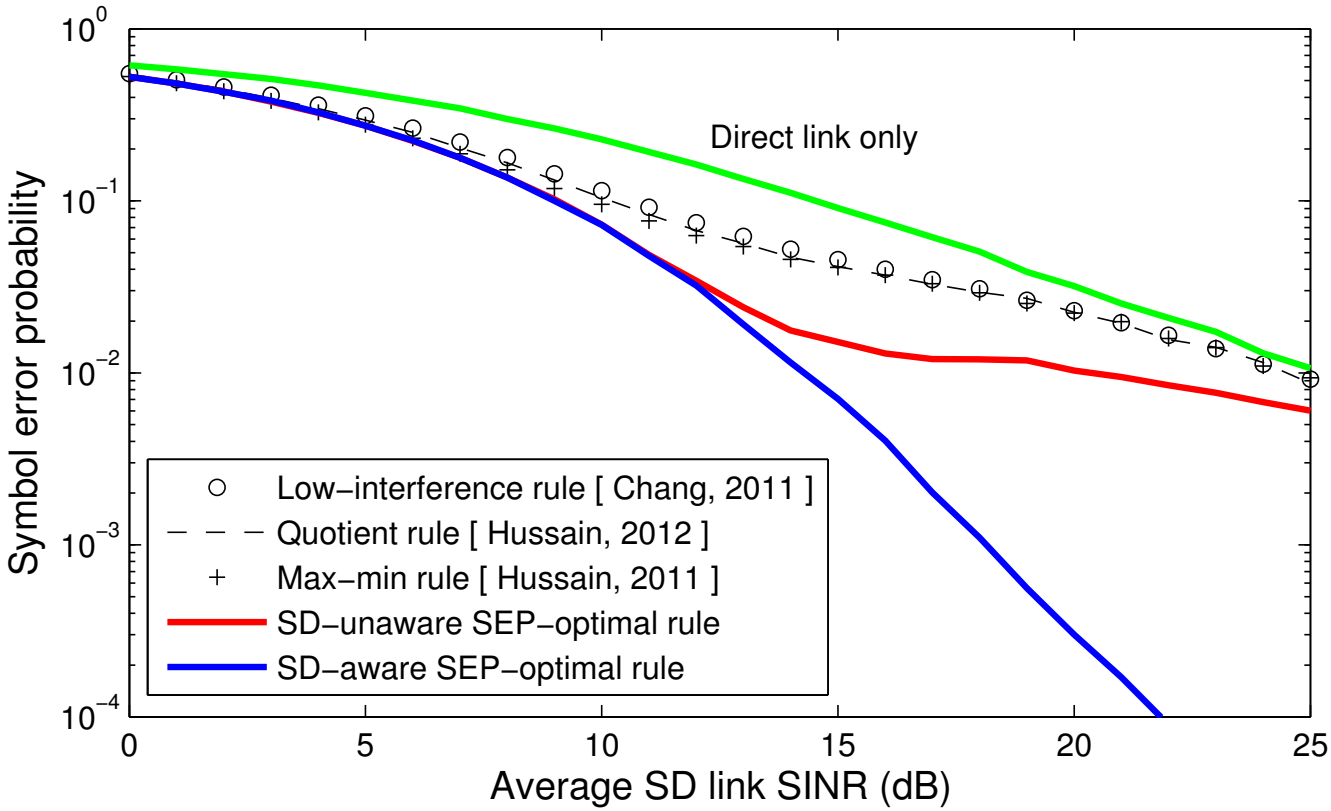
Minimize SEP

- Proposed SEP-optimal relay selection rule when relays
  - Not-aware of direct SD link state
  - Aware of direct SD link state
- Proposed simpler, sub-optimal rules
  - Analyzed average SEP and its high SNR expression
    - Diversity order analysis

Maximize Rate

- Proposed rate-optimal relay selection rule
- Analyzed its average rate
- Asymptotic rate analysis: For low and high SINRs

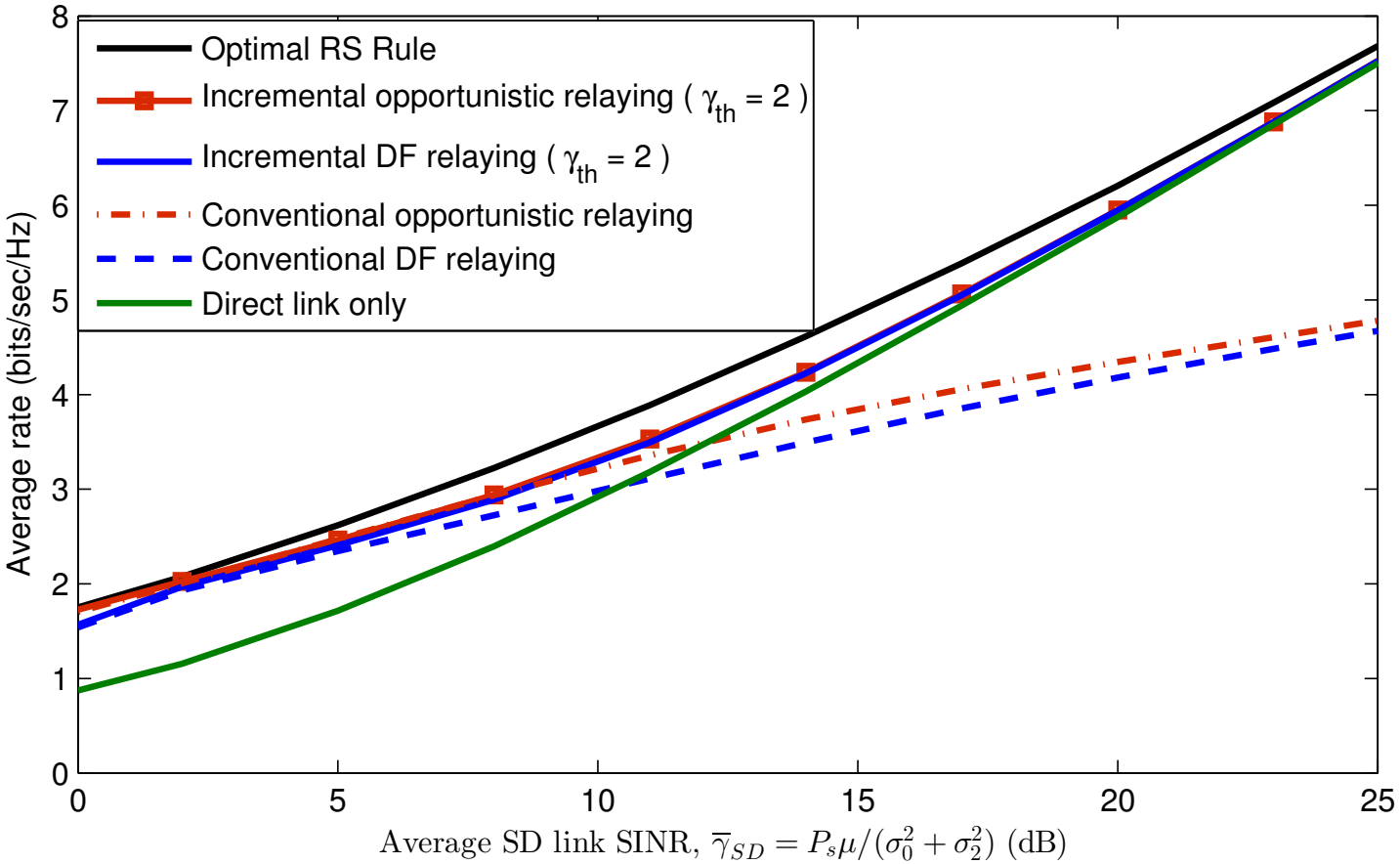
SEP Comparison and Benchmarking



- 8 PSK
- 4 relays
- $I_{\text{avg}} = 15$ dB

- Proposed schemes outperform other existing schemes
- SD link knowledge really helps to improve SEP

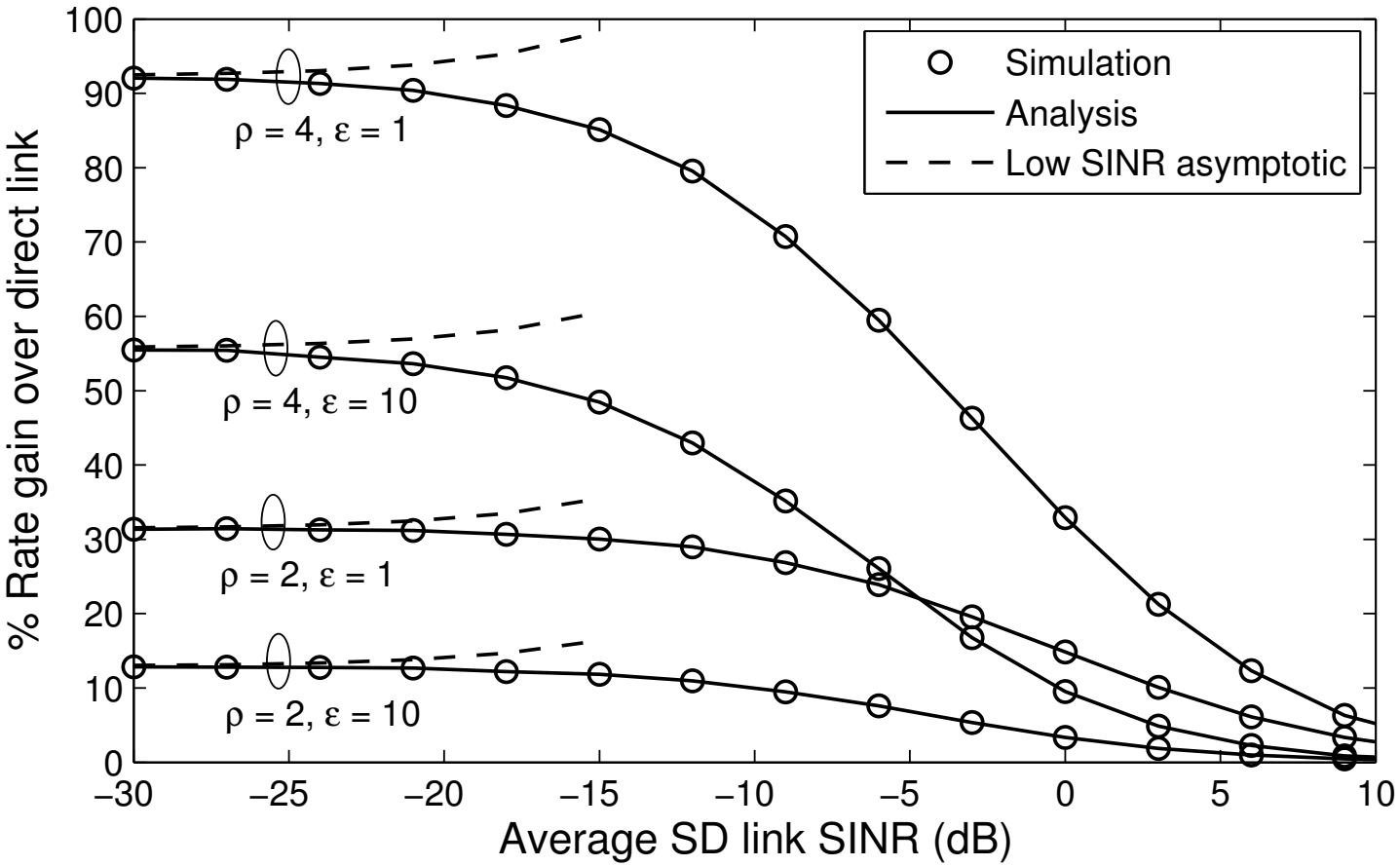
Rate Comparison and Benchmarking



- 4 relays
- $I_{\text{avg}} = 7$ dB

- Rate-optimal rule outperforms all other schemes for underlay CR

Rate Gain Over Direct Transmission



- 2 relays
- $\lambda = 0.1$
- $\rho = \frac{\mu_{SR}}{\mu_{SD}} = \frac{\mu_{RD}}{\mu_{SD}}$
- $\varepsilon = \frac{\mu_{RP}}{\mu_{SD}}$

- As SINR decreases, rate gain increases due to cooperation by relays
- Gain increases as relay links become stronger than SD link
- Gain decreases as interference link becomes stronger than the relay links

Summary

- Proposed optimal relay selection rule subject to average interference constraints
  - Optimizing SEP and rate
- Analyzed average SEP and rate with asymptotic insights
- Significant performance improvements over other schemes
  - Better understanding of when to use direct one-hop link
- Future Work
  - Extending to underlay CR with multiple primary receivers
  - Extending to full-duplex relaying in order to further improve rate

Publications

Journal Papers:

1. P. Das, N. B. Mehta, and G. Singh, "Novel relay selection rules for average interference-constrained cognitive AF relay networks," *IEEE Trans. Wireless Commun., vol. 14, no. 8, pp. 4304–4315, Aug. 2015*
2. P. Das and N. B. Mehta, "Direct Link-Aware Optimal Relay Selection and a Low Feedback Variant for Underlay CR," *IEEE Trans. Commun., vol. 63, no. 6, pp. 2044–2055, Jun. 2015*

Conference Papers:

1. P. Das and N. B. Mehta, "Direct Link-Aware Relay Selection for Average Interference-Constrained Underlay Cognitive Radio," *Proc. ICC, Jun. 2015*
2. P. Das and N. B. Mehta, "Revisiting Incremental Relaying and Relay Selection for Underlay Cognitive Radio," *Proc. Globecom, Dec. 2015*