Hybrid Relaying for the Parallel Relay Network

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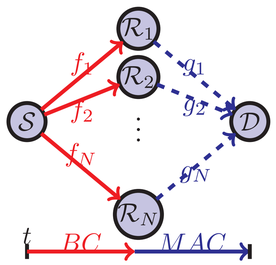
Problem

Multiple relays provide diversity in a wireless network. For cooperative transmission between a single source-destination pair, how do we communicate using the relays available?

- What relay behaviors are best?
- How should network resources be utilized?



We analyze the outage performance of hybrid relaying behavior for the parallel relay network.

Hybrid Relaying

We consider three different behaviors for the relays: **amplify-and-forward (AF)**, **decode-and-forward (DF)**, and **idle (inactive)**.

- $\mathcal{DF}$: set of nodes performing DF
- $\mathcal{AF}$: set of nodes performing AF

Let $K = |\mathcal{AF}|$ and $M = |\mathcal{DF}|$. Note that K and M are random variables.

Relay behavior is chosen based on threshold values, η_{df} and η_{af}.

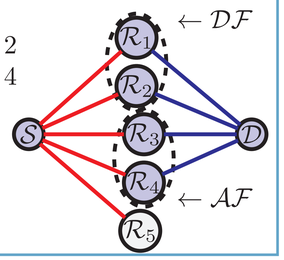
$$\begin{array}{ll} \eta_{df} \leq |f_i| & \Rightarrow \mathcal{R}_i \text{ performs DF} \\ \eta_{af} \leq |f_i| \leq \eta_{df} & \Rightarrow \mathcal{R}_i \text{ performs AF} \\ 0 \leq |f_i| \leq \eta_{af} & \Rightarrow \mathcal{R}_i \text{ is idle} \end{array}$$

For each transmission a random set of relays will be *active* (not *idle*).

Example:

$$\begin{array}{ll} \mathcal{R}_i \in \mathcal{DF} & i = 1,2 \\ \mathcal{R}_i \in \mathcal{AF} & i = 3,4 \\ \mathcal{R}_i \in (\mathcal{DF} \cup \mathcal{AF})^C & i = 5 \end{array}$$

$$K = M = 2$$



Assumptions and Constraints

We consider a parallel relay network with the following assumptions and resource constraints:

- i.i.d. Rayleigh fading channels with Gaussian noise
- CSI available at the receivers
- All nodes are half-duplex
- Fixed bandwidth for BC and MAC transmissions
- Relays have **peak** power constraints and **total** power constraint:

$$\begin{aligned} P_i &\leq P_i', \\ \sum_{i=1}^{N} P_i &\leq P_{tot}. \end{aligned}$$

Power Allocation

Without loss of generality, we assume that relays are ordered such that

$$\begin{aligned} &\mathcal{R}_i \in \mathcal{AF}, i = 1, ..., K, \\ &\mathcal{R}_i \in \mathcal{DF}, i = K+1, ..., K+M, \\ \text{and} \quad &|g_{K+1}| \geq |g_{K+2}| \geq \ldots \geq |g_{K+M}|. \end{aligned}$$

We consider two power schemes.

Equal Power

$$P_i = \begin{cases} \min\{\frac{\delta P_{tot}}{K}, P_i'\} & i = 1, ..., K \\ \min\{\frac{(1-\delta)P_{tot}}{M}, P_i'\} & i = K+1, ..., K+M \end{cases}$$

Optimized Power (requires feedback)

$$P_i = \begin{cases} \min\{P_i^*, P_i'\} & i = 1, ..., K \\ P_i' & i = K+1, ..., l-1 \\ r & i = l \\ 0 & \text{otherwise} \end{cases}$$

where P_i^* is the i^{th} component of the optimal power vector for AF relays and we can write

$$\sum_{i=K+1}^{l-1} P_i' + r = (1-\delta)P_{tot},$$

for some $l \leq K + M$.

Probability of Outage Results

Assuming Gaussian codebooks, the following are the instantaneous achievable rate expressions and probability of outage results produced via Monte-Carlo simulations. For regenerative (repetition) coding,

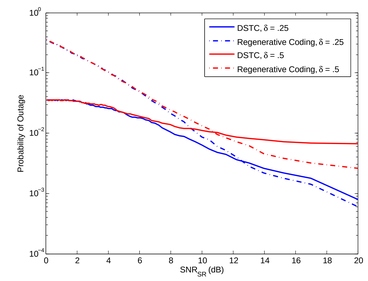
$$I_{REG}(X_S; \vec{Y}) = \log\left(1 + \frac{P_S}{W}\sum_{i=1}^{K}\frac{|g_i|^2|f_i|^2\beta_i^2}{|g_i|^2\beta_i^2 N_r + N_d} + \frac{N}{W}\sum_{i=K+1}^{K+M}\frac{|g_i|^2 P_i}{N_d}\right) \text{b/s/Hz.} \quad (1)$$

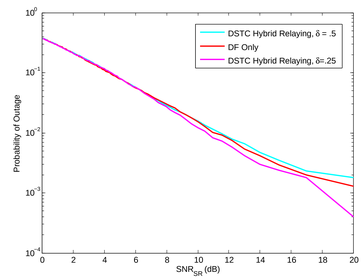
For distibuted space-time codes (DSTCs) at the relays in $\mathcal{DF}$,

$$I_{DSTC}(X_s; \vec{Y}) = \log\left(1 + \frac{N}{(N-K)W}\sum_{K+1}^{K+M}\frac{|g_i|^2 P_i}{N_d}\right) + \log\left(1 + P_s\sum_{i=1}^{K}\frac{|g_i|^2\beta_i^2|f_i|^2}{|g_i|^2\beta_i^2 N_r + N_d}\right) \text{b/s/Hz.} \quad (2)$$

Regenerative coding: All relays are allocated equal-size subchannels; transmissions are orthogonal in frequency. Relays in the set $\mathcal{DF}$ re-encode transmission using the same codebook as the source.

DSTC: Relays in the set $\mathcal{AF}$ transmit over equal-size subchannels, while relays in the set $\mathcal{DF}$ re-encode the source's transmission using DSTCs.





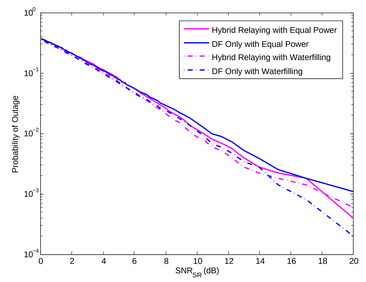


Fig.1 - Comparing DSTC and Regenerative coding for different values of δ. Optimal powers are used in all cases.

Fig.2 - Compare Hybrid Relaying with $\delta = .25$ and $.5$ with DF Only scheme. Equal power is allocated to all relays and DF use DSTCs.

Fig.3 - Compare Hybrid Relaying with DF Only Scheme, for both equal power allocation and optimal power allocation. DF relays use regenerative coding.

*$N = 4$ for all figures.

Conclusions

- Hybrid scheme outperforms decode-and-forward only protocol in some regimes
- New thresholding approach for relay selection which yields good results
- Derived power distributions maximizing achievable rate

Future Work

- Optimization of degrees of freedom
- Consider other relay behaviors
- Analyze hybrid relaying protocol using other metrics