Joint Source and Channel Coding for Cooperative Relaying

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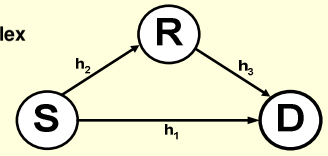
Problem Statement and Motivation

- Analog source over quasi-static Rayleigh fading channel
- Minimize end-to-end distortion
- Half-duplex relay available
- Delay requirements ⇨ expected distortion (ED)
- Source bandwidth ≠ Channel bandwidth
  ⇨ Analog transmission may not be optimal
- We analyze the high SNR behavior of expected distortion (ED) using distortion exponent:

$$\Delta = -\lim_{SNR\to\infty} \frac{\log(ED(R,SNR))}{\log(SNR)}$$

i.e., ED ~ SNR$^{-\Delta}$

- Memoryless, complex Gaussian source with unit variance
- h_1, h_2, h_3 independent, complex Gaussian with mean ½ each dimension and independent additive Gaussian noise at the receivers with variance N_0

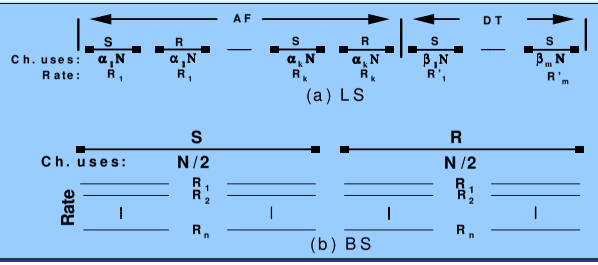


- K source samples in N channel uses during ⇨
  Bandwidth expansion ratio: b = N / K

Overview of Protocols

1) **Layered Source Coding (LS) :** Compress source in layers, each layer composed of the successive refinement bits, transmit layers successively in time at different rates. Relay only important layers by amplify-and-forwarding.
2) **Broadcast Strategy (BS) :** Compress source in layers, each layer composed of the successive refinement bits, transmit layers simultaneously at different rates by superimposing their codewords. Relay amplify-and-forwards.
3) **Uncoded Transmission (UT) :** Source is only scaled and transmitted.

*Application to direct channel can be found in [3].



Layered Coding Strategy for Cooperation

- Compress source in layers ⇨ Not all layers have same importance
  ⇨ Cooperate only for most important layers: "partial cooperation" [1]
- Two layer case: Base layer + Enhancement layer
  Base layer → Cooperate; Enhancement layer → Direct transmission
- Amplify-and-forward (AF) type relaying (can be extended to others)
- Outage probabilities:

Base: $P_{out}^1 \approx \left(\frac{2^{R_1}-1}{SNR}\right)^2$ Enhancement: $P_{out}^2 \approx \left(\frac{2^{R_2}-1}{SNR}\right)$

$$ED = (1-P_{out}^2)D(\alpha bR_1 + \beta bR_2) + (P_{out}^2 - P_{out}^1)D(\alpha bR_1) + P_{out}^1$$

Scale rates as: $R_i = r_i \log SNR, i = 1,2$

- In general m+k layers, cooperate on first k layers and remaining m layers are sent directly. In the limit we have

$$\lim_{\substack{m\to\infty \\ k\to\infty}} \Delta = \begin{cases} 1-e^{-b} & if \quad b \le \ln 3 \\ 2-4\cdot 3^{-3/4} e^{-b/4} & if \quad b > \ln 3 \end{cases}$$

Broadcast Strategy for Cooperation

- Quasi-static fading channel thought as a Gaussian broadcast channel with continuum of receivers, one for each fading level
- Superimpose source layers using broadcast codes
- The better the channel realization, the more layers decoded successfully, the less the end-to-end distortion is
- Power distribution among codewords of different layers
- Relay amplify-and-forwards all layers

* *Interference among layers is traded-off for increased multiplexing gain!*

$$\Delta = 2b\frac{(4^n - b^n)}{(4^{n+1} - b^{n+1})} \Rightarrow \lim_{n\to\infty}\Delta = \begin{cases} 4 & if \quad b \ge 4 \\ b/2 & if \quad b < 4 \end{cases}$$

Uncoded and Upper Bound for Cooperation

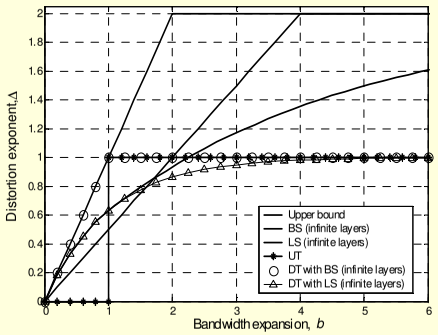
- In UT, cooperation possible for b≥2
- Optimum ML estimator at the destination

$$\Delta = \begin{cases} 0 & if \quad b < 1 \\ 1 & if \quad b \ge 1 \end{cases}$$

- For upper bound, assume perfect S-R channel and CSIT

$$\Delta = \begin{cases} b & if \quad b < 2 \\ 2 & if \quad b \ge 2 \end{cases}$$

Comparison of the Protocols

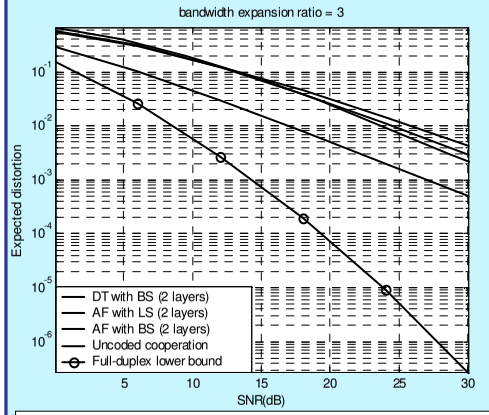


Distortion exponent depends on bandwidth expansion ratio:

- BS optimal for b≥4
- For b≥2 BS is the best strategy. Further improve possible by 'partial cooperation'
- Unlike direct transmission, UT not optimal ⇨ Analog transmission cannot adapt to more complex network structures

- *Performance improvement in BS over LS comes at the expense of a more complex encoder-decoder pair, as BS requires SNR-dependent power allocation among layers, superposition of codewords and sequential decoding.*

Numerical ED Results



Numerical results are compatible with theoretic values

High SNR analysis valid for even moderate SNR values

References:

[1] D. Gunduz, E. Erkip, "Joint source-channel cooperation: diversity versus spectral efficiency," Proc. of 2004 ISIT, Chicago, June 2004.

[2] D. Gunduz, E. Erkip, " Source and channel coding for cooperative relaying," *Proc. of 2005 SPAWC,* New York City, June 2005.

[3] D. Gunduz, E. Erkip, "Source and channel coding for quasi-static fading channels," Proc. of 39th Asilomar Conf. Signals, Systems and Computers, Pacific Grove, CA, October 2005.