Joint Source-Channel Cooperation: Diversity versus Spectral Efficiency

Deniz Gunduz, Elza Erkip[1]

Dept. of Electrical and Computer Engineering Polytechnic University, Brooklyn, NY 11201, USA

e-mail: `dgundu01@utopia.poly.edu elza@poly.edu`

Abstract — **User cooperation is a spatial diversity technique where multiple terminals form a virtual antenna array to combat fading. We incorporate source coding into the cooperation scenario and analyze cooperation protocols with respect to the average distortion they achieve. We first compare the amplify-and-forward (AF) protocol to direct transmission (DT) and show that it does not increase the performance in the average distortion sense. Then we propose two new cooperation protocols which achieve better performance by increasing the spectral efficiency while still providing diversity, yet maintaining the simple nature of the previous protocols.**

I. Analysis of Existing Protocols

We consider a zero-mean, unit variance, real Gaussian source which is compressed and transmitted over a flat, quasi-static Rayleigh fading channel with unit variance. In N channel uses, we transmit N compressed source samples. Our performance criterion is *expected distortion, ED* of the source. Let $P_{out}(R, SNR)$ denote the channel outage probability at rate R and the average received signal to noise ratio SNR. For DT, we have $ED(R, SNR) = (1 - P_{out}(R, SNR))2^{-2R} + P_{out}(R, SNR)$. For high SNR, considering a logarithmic growth $R = r \log SNR$, that is a multiplexing gain of r, we get $ED(R, SNR) \approx SNR^{-2r} + SNR^{r-1}$. Optimum performance is achieved for r=1/3. Defining the *average distortion exponent* as [2] $\triangle = \lim_{SNR\to\infty} \frac{-\log(ED(R,SNR))}{\log(SNR)}$ and using the optimal multiplexing gain r=1/3, we get $\triangle$= 2/3 for DT.

We now consider two cooperating partners with a common destination. We define AF as in [1]. Source still transmits with rate R bits/channel use, but due to the loss in spectral efficiency (only half of the time slots are used by the source), source coding rate is reduced to R/2 bits/sample which results in increased distortion. High SNR analysis shows that optimal r=2/3 and $\triangle$=2/3.

The incremental relaying (IR) protocol [1] provides higher spectral efficiency at the expense of feedback from destination. We slightly modify IR, utilizing the successively refinable nature of the Gaussian source. Now in case of successful transmission in the first time slot, the source transmits the successive refinement bits achieving distortion D(R). The optimum values for IR are r=1/2 and $\triangle$=1. These results together with Fig. 1 show that the AF does not provide a better performance than DT for neither low nor high SNR values due to the decrease in spectral efficiency despite the fact that it offers two levels of diversity. IR results in better performance but requires feedback.

II. New Protocols

Based on the above observations, we propose *partial cooperation* (PC) protocol that can provide a trade-off between spectral efficiency and diversity. In this protocol, N source samples are first coded with βR bits/sample, where $0 \leq \beta \leq 1/2$.

[1]This work was partially supported by Philips Research

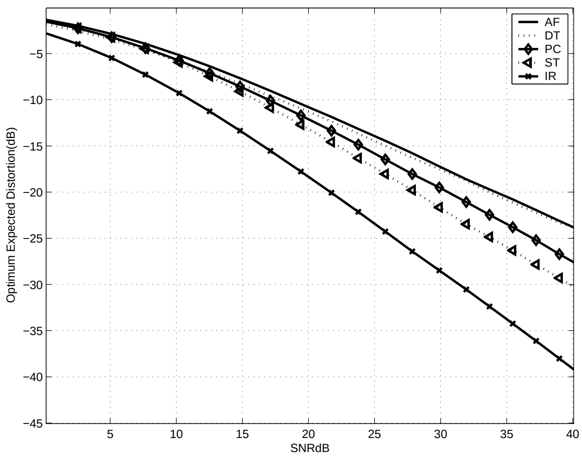

Figure 1: Expected distortion vs. SNR for different protocols

These bits are transmitted first by the source in βN channel uses, with R bits/channel use, and then amplified and forwarded by the relay again in βN channel uses, with R bits/channel use. In the rest of the source time slot, that is in $(1 - 2\beta)$N channel uses, $(1 - 2\beta)$R bits/sample successive refinement bits about the source are directly transmitted by the source with no cooperation. Note that DT and AF protocols are special cases of PC protocol for β=0 and β=1/2, respectively. If we analyze the high SNR behavior of the PC protocol, the average distortion exponent is optimized for β=1/3. This results in optimal multiplexing gain of r=3/5 and optimal average distortion exponent $\triangle$=4/5.

More advanced protocols that improve both spectral efficiency and diversity without resorting to feedback may include multiple access schemes. In the simplest case which we call *cooperation by simultaneous transmission* (ST) source transmission in the first half of the time slot remains same (again R/2 bits/source sample) while in the second half, source and relay transmit together with half of the power of the previous protocols resulting in the same total power. While the relay is forwarding, the source transmits the successive refinement bits, that is additional R/2 bits/sample. The second half of the time slot results in a multiple access channel and decoding in the destination is done by successive interference cancellation for simplicity. It can be seen from Fig. 1 that ST achieves better performance than any other protocol without feedback.

References

[1] J. N. Laneman, D. N. C. Tse, and G. W. Wornell, "Cooperative diversity in wireless networks: Efficient protocols and outage behavior," *IEEE Trans. Inform. Theory*, accepted.

[2] J. N. Laneman, E. Martinian, G. W. Wornell, J. G. Apostolopoulos, and S. J. Wee, "Comparing application- and physical-layer approaches to diversity on wireless channels," in Proc. IEEE ICC, (Anchorage, Alaska), May 2003.