Source-Channel Diversity Approaches for Multimedia Communication

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I. Introduction

In wireless links, fading, shadowing, interference, and congestion can cause the channel quality to fluctuate dramatically. Practical systems have often been designed to combat channel uncertainty by exploiting diversity either at the physical layer via channel coding (*e.g.*, space/time/frequency diversity) or at the application layer via source coding (*e.g.*, multiple descriptions coding). We compare these approaches for continuous sources with quadratic distortion.

II. System Model

Consider the system block diagram shown in Fig. 1. A source signal $\mathbf{s}$ is quantized and transmitted over two parallel channels. We model the source as a sequence of n_s independent, identically distributed samples drawn according to the distribution $p_s(s)$. Similarly, we consider a channel model consisting of two independent branches each with a separate state a_i representing block fading, shadowing, *etc.* Specifically, if $\mathbf{x}_1$ and $\mathbf{x}_2$ each correspond to a block of n_c samples used as input to the first and second branches of the channel, then the pair of channel output blocks $\mathbf{y}_1$ and $\mathbf{y}_2$ are drawn according to

$$\sum_{a_1,a_2} p_{\mathsf{a}}(a_1)\cdot p_{\mathsf{a}}(a_2)\prod_{i=1}^{n_c} p_{\mathsf{y}|\mathsf{x},\mathsf{a}}(y_{1,i}|x_{1,i},a_1)\cdot p_{\mathsf{y}|\mathsf{x},\mathsf{a}}(y_{2,i}|x_{2,i},a_2).$$

The transmitter knows the distribution of each random variable but must choose the inputs without knowledge of the channel state. The receiver obtains $(\mathbf{y}_1,\mathbf{y}_2,\mathsf{a}_1,\mathsf{a}_2)$. We denote the bandwidth expansion ratio or processing gain n_c/n_s as ζ. Finally, when the receiver produces the estimate $\hat{\mathbf{s}}$ from the channel output, the distortion is $D(\mathbf{s},\hat{\mathbf{s}})=\sum_{i=1}^{n_s}(\hat{\mathsf{s}}_i-\mathsf{s}_i)^2$.

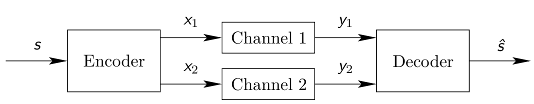

Figure 1: Source-channel diversity system model.

III. Main Result

We characterize how average distortion decays with SNR. Specifically, we consider channels where the exponential of the block mutual information $\exp[\mathsf{I}(\mathbf{x}_i;\mathbf{y}_i)]$ has a cumulative distribution function $F_{e^I}(t)$ which can be approximated by

$$F_{e^I}(t)\approx c\left(\frac{t}{\mathrm{SNR}}\right)^p \text{ (with } p\geq 1). \tag{1}$$

Essentially, p represents the inherent diversity in each sub-channel. For example, in a Rayleigh fading additive white Gaussian noise channel with power constraint SNR, the distribution for $\exp[\mathsf{I}(\mathbf{x}_i;\mathbf{y}_i)]$ is like (1) with $c=p=1$. If each sub-channel corresponds to coding over two fades, then $p=2$.

For channels with (1), distortion behaves like $\mathrm{SNR}^{-\Delta}$ for high SNR. Hence we characterize various system architectures by computing the distortion exponent defined as

$$\Delta=\lim_{\mathrm{SNR}\to\infty}-\frac{\log E[D]}{\log \mathrm{SNR}}. \tag{2}$$

In [1] we compute the distortion exponents listed below for:

Channel Coding Diversity: A classical single description source coder quantizes the source.

- *Selection Diversity.* The quantization is channel coded and repeated across two independent channels. The receiver decodes the best channel and ignores the other.
- *Channel Multiplexing.* The quantization is split into two equal pieces each of which are independently channel coded. The receiver must decode both channels successfully to recover the quantization.
- *Optimal Diversity.* The quantization is jointly channel coded. The receiver decodes both channels jointly and reconstructs the quantization if successful.

Source Coding Diversity: A multiple description source coder quantizes the source into two descriptions.

- *Separate Decoding.* Each description is independently channel coded. The decoder decodes each channel separately and passes the result to the source decoder.
- *Joint Decoding.* Each description is independently channel coded. The decoder jointly decodes the channel codes by specifically taking into account the redundancy induced by the multiple description encoding.

System	Δ
No Diversity	$2\zeta p/(2\zeta+p)$
Channel Diversity (Selection)	$2\zeta p/(\zeta+p)$
Channel Diversity (Multiplexing)	$4\zeta p/(4\zeta+p)$
Channel Diversity (Optimal)	$4\zeta p/(2\zeta+p)$
Source Diversity (Separate Decoding)	$\max[8\zeta p/(4\zeta+3p),$ $4\zeta p/(4\zeta+p)]$
Source Diversity (Joint Decoding)	$4\zeta p/(2\zeta+p)$

The distortion exponents show that optimal channel diversity outperforms source diversity with separate decoding. This gap is not due to an inherent flaw in multiple descriptions *encoding* but instead results from the rigid layering between source and channel *decoding*. Finally, source diversity is superior to sub-optimal channel diversity. Thus, the decision of which system to use should be based on both the benefits of a large Δ as well cost, flexibility, ease of implementation, *etc.*

References

[1] J. N. Laneman, E. Martinian, G. W. Wornell, and J. G. Apostolopoulos, "Source-Channel Diversity Approaches for Multimedia Communication" *submitted to IEEE Trans. on Inform. Theory.*

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