Non-asymptotic Variable-Length Coding with Feedback: Rate-Compatible Sphere-Packing

Tsung-Yi Chen, Adam Williamson and Richard Wesel

University of California, Los Angeles Electrical Engineering Department

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Outline

1 Introduction

- Previous Work
- Variable-Length Feedback Codes with Termination

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- Fixed-to-Variable codes
- 2 Analyses of Non-asymptotic Feedback Codes
 - Overview
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- 3 Analytic and Experimental Observations
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4 Conclusion



• Feedback is very useful for time-varying channels.



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- Under regular conditions we have V = Var[i(X; Y)], $\mathbb{E}[i(X; Y)] = C$ and the following approximations:

$$R(n,\epsilon) \approx C - \sqrt{\frac{V}{n}}Q^{-1}(\epsilon) + \frac{O(\log n)}{n} \quad \text{w.o. feedback}$$
$$R_{\text{FB}}(n,\epsilon) \approx \frac{C}{1-\epsilon} + \frac{O(\log n)}{n} \quad \text{with feedback}$$

[PPV'10, PPV'11]

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- Error exponent analysis does not capture the performance variation seen at short block lengths.
- Evidence: ARQ + good block codes achieve the optimal Burnashev error exponent.
- There is a considerable performance gap between ARQ codes and the best VLFT codes.

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 - 4 A stopping time τ w.r.t. the filtration $\mathcal{F}_n = \sigma\{Y^n, W\}$ s.t.

$$\mathbb{E}[au] \leq \ell \ \mathbb{P}[\hat{W}
eq W] \leq \epsilon, \hat{W} = g_ au(Y^ au)$$



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$$\tau = \inf\{n \ge 1 : g_n(Y^n) = W\}.$$
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- Implications:
 - (1) The receiver knows whether the decoded message is correct and hence knows when to terminate.
 - (2) The encoders only use feedback to decide whether to transmit more coded symbols or stop (stop-feedback codes).
 - (3) FV codes are zero-error VLFT codes.

• For systems where error detection is handled in a higher protocol layer than the physical layer, FV codes are widely used.

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- For achievability with no input constraint, Polyanskiy et al. use i.i.d. input distribution to generate the random codes.
- We use rate-compatible sphere-packing (RCSP) to analyze FV codes with finite and infinite number of transmissions.
- Both analyses show very fast convergence to capacity.
- Random coding performs similar to RCSP at large expected block length regime.

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 - 5 If $m = \infty \Rightarrow I_j = 1 \ \forall j \ (\text{VLFT achievability } [PPV'11]).$
 - 6 We will focus on the memoryless AWGN channel with an averaged power constraint for the rest of the talk.



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Random Coding Lower Bound

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- For a message $w \in W$, the encoder $f_n(w)$ output $(c_w)_n$, the *n*th coordinate of the codeword c_w .
- For VLFT codes the decoder can apply ML decoding and decide whether to stop according to *W*: *τ* = inf{*n* ≥ 1 : *g_n*(*Yⁿ*) = *W*}.

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The coding scheme when $m < \infty$ can be adjusted accordingly.

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- Assume at each blocklength the code achieves sphere packing.



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- Perform a bounded-distance decoding for the received symbols.



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- Assume at each blocklength the code achieves sphere packing.
- Perform a bounded-distance decoding for the received symbols.
- The stopping time is the same: $\tau = \inf\{n \ge 1 : g_n(Y^n) = W\}.$
- For the Gaussian channel with a sequence of radii $\{r_i\}_{i=1}^n$, the stopping time is $\tau = \inf\{n \ge 1 : \sum_{j=1}^n Z_j^2 < r_n^2\}, Z_j \sim \mathcal{N}(0, 1).$



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Figure : RCSP approximations, VLFT random coding lower bound, and convolutional code simulation over binary-input AWGN channel.

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Figure : RCSP approximation for various m.

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- The total number of transmissions *m* for a message provides diminishing returns as *m* grows.
- A small *m* with optimized lengths of incremental transmissions is good enough.
- It is best to send the non-repetitive coded symbols, i.e., send fresh new coded symbols.
- For a fixed *m*, finding a FV code is equivalent to finding a good family of rate-compatible codes.

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Some remaining problems that need to be solved:

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 - Design a family of good rate-compatible codes in a moderate-blocklength regime.

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- Non-asymptotic analysis for VLFT codes lead to some new challenges in code design:
 - Design a family of good rate-compatible codes in a moderate-blocklength regime.
 - 2 Fine-tuning the tradeoff between error correction/detection.

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 RCSP captures the benefit of feedback and matches well with some good codes.

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- A randomly punctured convolutional code outperforms random coding and is close to RCSP in the 100-bit blocklength regime.
- When the termination cost is included, we need to investigate codes that are good in the moderate-blocklength regime.

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Questions?



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