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The role of arithmetic coding based continuous error detection in digital transmission systems

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Abstract — **A "continuous" error detection scheme based on arithmetic coding ideas is analyzed. The results show significant gains of the proposed scheme over conventional block error detection codes (e.g., CRC) for Automatic Repeat ReQuest (ARQ), Forward Error Correction (FEC) and Hybrid ARQ schemes.**

I. INTRODUCTION

As should be true for all good source compressors, a single error in an entropy coded stream proves to be catastrophic for the rest of the stream. Surprisingly, such catastrophic behavior (usually considered to be a disadvantage) is well suited for error detection coding. The novel idea of continuous error detection (CED) based on arithmetic coding was first introduced by Boyd et al. in [1], albeit with little system performance analysis, or exposition of its utility in "real" communication systems. The basic idea consists of adding, to the list of data symbols to be arithmetically encoded, an extra "forbidden" symbol that is never actually transmitted, but for which a controlled amount of probability space is reserved nonetheless. If data is corrupted, there is a possibility of decoding the forbidden symbol and thus detecting the presence of error(s). By controlling the amount of coding space that the forbidden symbol occupies, it is possible to make statistical guarantees about *where the errors may have occurred.* This is useful in communication scenarios like ARQ, concatenated FEC coding systems having an error-detection "outer" component. In an ARQ system, the utility comes from the ability to make statistical statements relating the time of error occurrence to the time of its detection, resulting in potential savings in the number of bits that need to be retransmitted when an error is detected. In a serially concatenated coding system using inner convolutional codes, the use of CED can likewise be useful to eliminate invalid trellis paths, leading to potential performance gains for list Viterbi Algorithm schemes [2].

II. ERROR DETECTION VIA ARITHMETIC CODING

Encoding and decoding via the arithmetic coder proceed by repetitively partitioning subintervals within the unit interval $[0,1)$ according to the probabilities of the data symbols. If we introduce a forbidden symbol that is never encoded by the arithmetic coder, but nonetheless occupies a nonzero measure ϵ on the set $[0,1)$, then upon decoding, if an error occurs, this forbidden symbol is likely eventually be decoded. A simple geometric distribution is a good model for the number of encoded bits n between an error and its detection, i.e., $Prob(n=k)=\epsilon(1-\epsilon)^{k-1}, \quad k=1,2,3....$ This detection time is inversely related to the amount of redundancy ($-log_2(1-\epsilon)$ bits per encoded symbol) added through introducing the forbidden symbol. Thus, the *detection speed can be continuously traded for the redundancy.* The geometric model is used to obtain analytically the optimal ϵ and the corresponding performance of ARQ systems in Fig. 1.

III. APPLICATIONS OF CONTINUOUS ERROR DETECTION

The throughput performance of the proposed and conventional ARQ schemes are compared in Fig. 1. For fair comparison an optimal packet size is used for the reference ARQ system. Accordingly, the optimal ϵ was also found and used for each of the bit-error probabilities tested using our new method of ARQ. Our preliminary results indicate similar gains for the Hybrid ARQ systems with punctured convolutional codes and list Viterbi decoding. An additional advantage of proposed error detection method is the capability of implementing it in the same "device" as the source coder, e.g., in the image and video communication systems which use arithmetic coding for compression. Furthermore, the proposed method of CED is well-suited for time-varying environments, because ϵ can be continuously adapted as a function of the channel and source parameters. More details about CED may be found at:

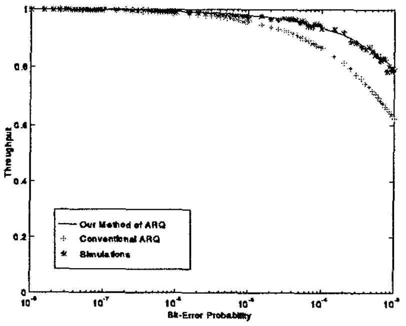

Figure 1: Throughput curves of our new method of ARQ versus conventional ARQ.

`http://www.ifp.uiuc.edu/~igor/html/publication.html`

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[2] N. Seshadri and C. Sundberg, "List Viterbi decoding algorithms with applications," *IEEE Trans. on Commun.*, vol. 42, pp. 313-323, 1994.

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