# How to Simplify Channel-Optimized Vector Quantization for Time-Varying Channels

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Channel-Optimized Vector Quantization (COVQ, [1]) achieves strong quality-improvements over "normal" Vector Quantization (VQ) if the transmission channel is noisy. The problem addressed in this paper is how to limit the memory and complexity requirements on *time-varying* channels to the extent known from "normal" VQ, while keeping good performance close to that of optimally matched COVQ for all channel conditions.

The distance measure which is used in COVQ differs from the one in "normal" VQ because transitions from the transmitted indices $i$ to some (possibly other) indices $j$ at the receiver occur with probabilities $P_{j|i}$ that depend on the channel. These probabilities are used in the COVQ-encoder to minimize the expected distortion at the receiver due to the quantization decision, i.e., the *COVQ distance measure* is given by

$$d_{covq}(x, y_i) = \sum_{j=0}^{N_C-1} P_{j|i} \cdot d_{vq}(x, y_j) \ , \qquad (1)$$

where $x$ is the data-vector to be quantized, $y_i$ is the codevector with the number $i = 0, 1, ..., N_C-1$, $N_C$ is the number of codevectors, and $d_{vq}(x, y_j)$ is the distance measure (e.g., the mean squared error) used in "normal" VQ.

If the channel is time-varying the channel-optimized codebook might not be matched to the current channel statistics. One possible way to improve the performance in such a situation is to switch between different codebooks depending on the current channel state [2]. However, this strategy requires the storage of several codebooks at both the encoder and the decoder.

In Figure 1, codebooks with $N_C = 32$ two-dimensional codevectors are depicted which were designed for a strongly autocorrelated Gauss-Markov-source. The plots show the codevectors

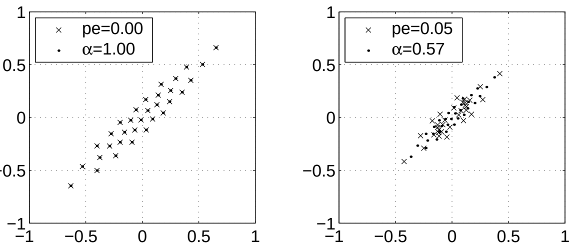


Fig. 1. Comparison of COVQ-codebooks ("×") and CASVQ-codebooks ("·"). The codebooks in the left plot are both identical to a "normal" VQ-codebook.

(marked by "×") that result from the training procedure for COVQ-codebooks [1] for two assumptions of the bit error probability $p_e$ on a binary symmetric channel. Regarding only the rough "shape", a COVQ-codebook for $p_e = p_1 > 0$ can be viewed as a shrinked version of a COVQ-codebook with $p_e \leq p_1$.

This observation leads to the basic idea of *Channel-Adaptive Scaled Vector Quantization (CASVQ)*: Codevectors $y_i^{(r)}$ from a reference COVQ-codebook are scaled by a channel-dependent factor $\alpha(p_e) \neq 1$ if the channel does *not* match the training assumption for the reference codebook, i.e., the CASVQ-codevectors are given by

$$y_i^{'(p_e)} = \alpha(p_e) \cdot y_i^{(r)} \ . \qquad (2)$$

As an example, CASVQ-codevectors (marked by "·") are included in Figure 1, which have been derived from the reference codebook in the left plot (COVQ-codebook designed for $p_e = 0$) by the scaling factors $\alpha$ stated in the legends.

The optimal function $\alpha = f(p_e)$ is individual for the codebook and can be determined by simulations. Although the memory requirements are strongly reduced by CASVQ compared to COVQ (which uses a different codebook for each channel state), the problem of the higher complexity for the computation of the COVQ distance measure remains: Since both the COVQ- and the CASVQ-codevectors are adapted to the time-varying channel, the efficient calculation of the COVQ distance measure by use of precomputed intermediate results [1] requires additional complexity, because a re-computation is needed after each channel-adaptation. In order to save this complexity one can use the "normal" VQ distance measure in CASVQ ("CASVQ, vq-dist."). In this case, all we have to do additionally compared to "normal" VQ is to scale the input data vector $x$ by $\frac{1}{\alpha}$. Also, a small table is required to represent the function $\alpha = f(p_e)$. The rest is completely the same as in "normal" VQ including the memory requirements.

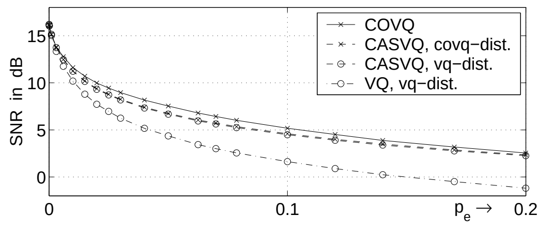


Fig. 2. SNR-Performance of COVQ, CASVQ, and VQ versus the bit error probability $p_e$. The COVQ-codebooks and the CASVQ-codebooks are matched to the true value of $p_e$ on the channel.

Figure 2 shows the numerical results. As to be expected, COVQ works best but there is only a moderate difference between "COVQ" and "CASVQ, vq-dist.". Therefore, CASVQ allows a very simple, memory-efficient, and low-complexity adaptation of a VQ coding-scheme to time-varying channels with a performance close to that of optimally matched COVQ.

## References

[1] N. Farvardin and V. Vaishampayan, "On the performance and complexity of channel-optimized vector quantizers," *IEEE Transactions on Information Theory*, vol. 37, no. 1, pp. 155–160, Jan. 1991.

[2] H. Jafarkhani and N. Farvardin, "Channel-matched hierarchical table-lookup vector quantization for transmission of video over wireless channels," in *Proceedings of the IEEE International Conference on Image Processing (ICIP)*, Sept. 1996, pp. 755–758.