Joint Optimization of the Perceptual Core and Lossless Compression Layers in Scalable Audio Coding

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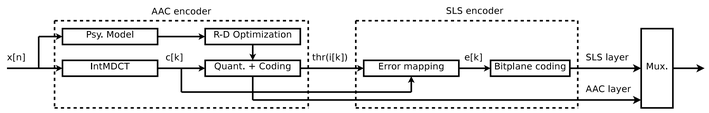
MPEG-4 HD-AAC

- A scalable-to-lossless (SLS) codec with perceptual (lossy) AAC core + fine-grained enhancements (cumulatively lossless)
- Integrated solution for playback, streaming, archiving, etc.



Current encoding approach

- First, optimize AAC base-layer. Subsequently, choose SLS encoding parameters.
- Separate optimization ignores inter-layer dependence.
- Optimal AAC layer $\Rightarrow$ good perceptual quality, but at cost to lossless compression
- SLS non-core $\Rightarrow$ optimal lossless compression, but poor perceptual quality at low bit-rates

Proposed method

- Optimal selection of AAC parameters with an explicit accounting of effect on subsequent SLS coding
- A framework for trade-off between AAC perceptual quality and SLS lossless compression
- R-D optimization formulated as:

$$\mathcal{P}^* = \arg \min_{\mathcal{P}:\mathcal{D}_b(\mathcal{P})\leq\mathcal{D}_t} \mathcal{R}_b(\mathcal{P}) + \alpha\mathcal{R}_e(\mathcal{P})$$

- where
  - $\mathcal{P}$: set of AAC parameters - scalefactors (SFs) + Huffman codebooks (HCBs) - for all frames
  - $\mathcal{R}_b(\mathcal{P})$: AAC bit-rate given parameters $\mathcal{P}$
  - $\mathcal{R}_e(\mathcal{P})$: bit-rate for the optimal SLS layer when the base-layer is encoded with parameters $\mathcal{P}$
  - $\mathcal{D}_b(\mathcal{P})$: achieved distortion in the AAC layer
  - $\mathcal{D}_t$: target distortion in the AAC layer
  - α : parameter that controls the AAC-SLS performance trade-off
- Definition of $\mathcal{R}_e(\mathcal{P})$ subsumes optimization over SLS parameters $\Rightarrow$ *jointly optimized AAC and SLS layers*.

Distortion measures

- Average-Average NMR (AANMR):

$$\mathcal{D}_b^A(\mathcal{P}) = \frac{1}{N}\sum_{n=0}^{N-1}\frac{1}{L}\sum_{l=0}^{L-1} d_n^l(s_n^l)$$

- Maximum-Maximum NMR (MMNMR):

$$\mathcal{D}_b^M(\mathcal{P}) = \max_{0\leq n<N}\max_{0\leq l<L} d_n^l(s_n^l)$$

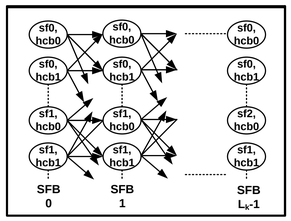
- $d_n^l(s_n^l)$: NMR in scalefactor band *l* of frame *n*, when corresponding scalefactor is s_n^l

MMNMR solution

- Equivalent per SFB distortion constraint: $d_n^l(s_n^l) \leq \mathcal{D}_t$
- Equivalent problem (for each frame n):

$$\mathrm{p}_n^* = \arg \min_{\mathrm{p}:d_n^l(s^l)\leq\mathcal{D}_t} \mathrm{R}_b^n(\mathrm{p}) + \alpha\mathrm{R}_e^n(\mathrm{p})$$

- where p, $\mathrm{R}_b^n(\mathrm{p})$, and $\mathrm{R}_e^n(\mathrm{p})$ represent, respectively, per-frame AAC parameters, AAC bit-rate, and SLS bit-rate.
- Computationally efficient search for p_n^* via trellis-based approach
- Stages of the trellis: scalefactor bands
- Nodal parameters : AAC SCFs and HCBs, and SLS MSB-planes and optimal lazy bit-planes



- Nodal costs: AAC distortion, and bits for encoding AAC spectral data, SLS residual, and lazy bit-plane parameters
- Transition costs: bits for encoding SCFs and HCBs (in AAC), and MSB-planes (in SLS)
- Best path via Viterbi algorithm

AANMR solution

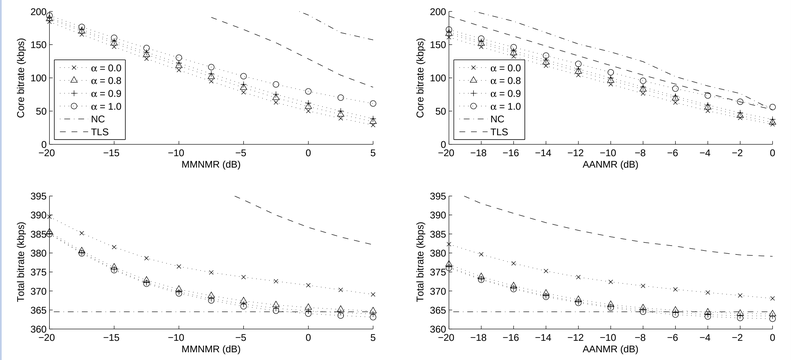
- Follows the Lagrangian technique: minimize

$$\mathrm{J}_n(\mathrm{p}_n, \lambda) = \mathrm{R}_b^n(\mathrm{p}_n) + \alpha\mathrm{R}_e^n(\mathrm{p}_n) + \lambda\left(\frac{1}{L}\sum_{l=0}^{L-1} d_n^l(s_n^l)\right)$$

- Solution via similar trellis-based search
- Lagrange parameter λ adjusted till $\mathcal{D}_t$ achieved

Evaluation

- Codecs compared: SLS non-core (NC), TLS-based HD-AAC, proposed coding scheme
- Test set: 15 audio files, 30s each, mono, 48 kHz
- R-D curves with distortion-constrained (AANMR or MMNMR) base-layer at different α values



- Objective quality (PEAQ), total bit-rate, and compression ratio evaluated for rate-constrained base-layer at 64kbps

	PEAQ ODG	Total bit-rate	Compr. ratio
MMNMR α=0.00	-0.942	368.7	2.083
MMNMR α=0.92	-0.957	361.3	2.125
MMNMR α=1.00	-1.919	360.0	2.133
AANMR α=0.00	-0.885	367.0	2.093
AANMR α=0.79	-1.125	361.4	2.125
AANMR α=1.00	-2.060	359.7	2.135
TLS	-1.676	376.3	2.041
SLS non-core	-1.923	361.4	2.125

Conclusions

- A novel trellis-based algorithm for joint optimization of SLS and AAC encoding parameters in HD-AAC is proposed
- Facilitates a trade-off between lossless compression ratio and perceptual quality at intermediate bit-rates
- Contrary to popular opinion, inclusion of AAC core need not preclude excellent lossless compression performance

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