A Full Bandwidth Audio Codec with Low Complexity and Very Low Delay

Jean-Marc Valin, Octasic Inc.
Timothy B. Terriberry, Xiph.Org Foundation
Gregory Maxwell, Juniper Networks Inc.

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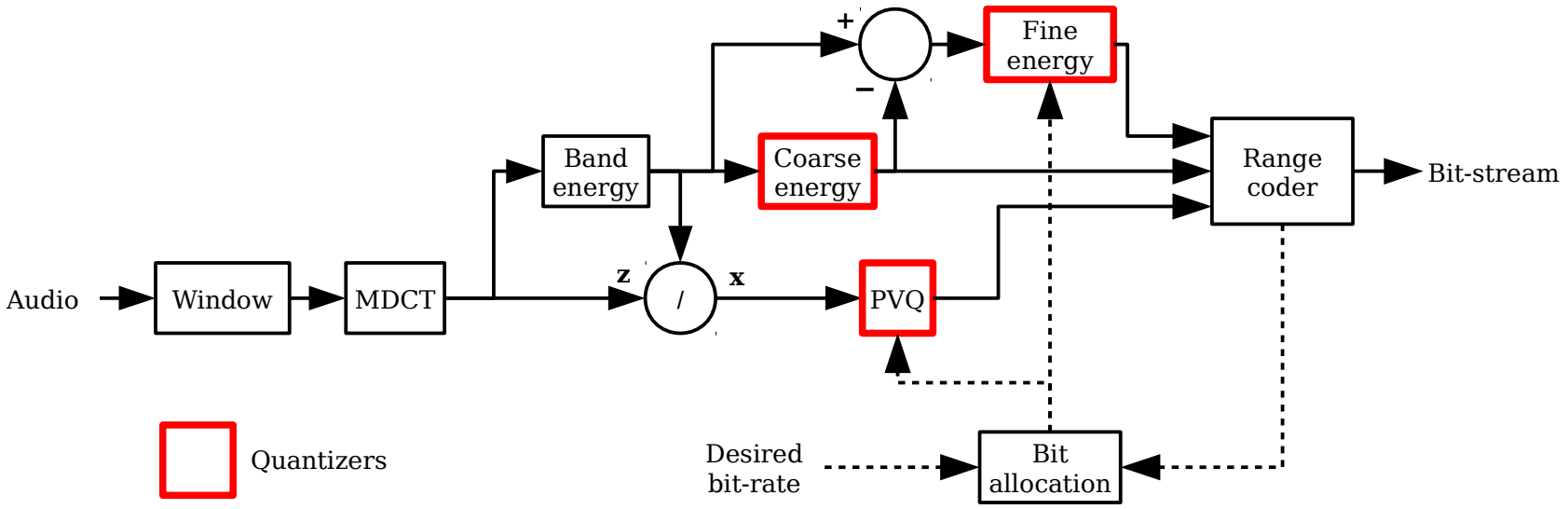
Introduction

- **Motivations for very low delay**
  - Delay-sensitive applications (e.g. live network music)
  - Reduces perception of acoustic echo
- **Codec characteristics**
  - Speech and music at 48 kHz
  - 5.3 ms frame size (256 samples), 2.7 ms look-ahead
  - 48-128 kb/s per channel (adaptive)
  - Support for frames sizes of 64 – 512 samples

Overview

- **Constrained-Energy Lapped Transform (CELT)**
- **Basic principles**
  - MDCT spectrum divided into critical bands
  - Band energy explicitly coded, constrained at decoder
  - Spectral “details” coded with spherical codebook
  - Bit allocation based on shared information

Encoder Block Diagram



Transform, Bands

- **Modified Discrete Cosine Transform (MDCT)**
  - Low-overlap window
  - Divided into critical bands (except low frequencies)
- **Implications of short frame size**
  - Poor frequency resolution and leakage
  - High cost of “side information”

Energy Quantization

- **Energy computed for each critical band**
- **Coarse-fine strategy**
  - Coarse energy quantization
    - Scalar quantization with 6 dB fixed resolution
    - Prediction in time (previous frame) and frequency
    - Range-coded with Laplacian probability model
  - Fine energy quantization
    - Variable resolution (based on bit allocation)
    - Not entropy-coded
- **Any error in the energy quantization is <u>not</u> compensated in the later quantization stages**

PVQ Codebook

- **Quantizing *N*-dimentional vectors of unit norm**
  - *N*-1 degrees of freedom (hyper-sphere)
- **Pyramid Vector Quantizer [Fischer, 1986]**
  - Algebraic codebook (no table stored)
  - Combinations of *K* signed “pulses”
  - Set of vectors *y* such that $\| y \|_{L1} = K$
  - Mapped onto the hyper-sphere: $x = y / \| y \|_{L2}$
- **Fast search and indexing algorithms**
- **Index is range-coded (flat probability)**

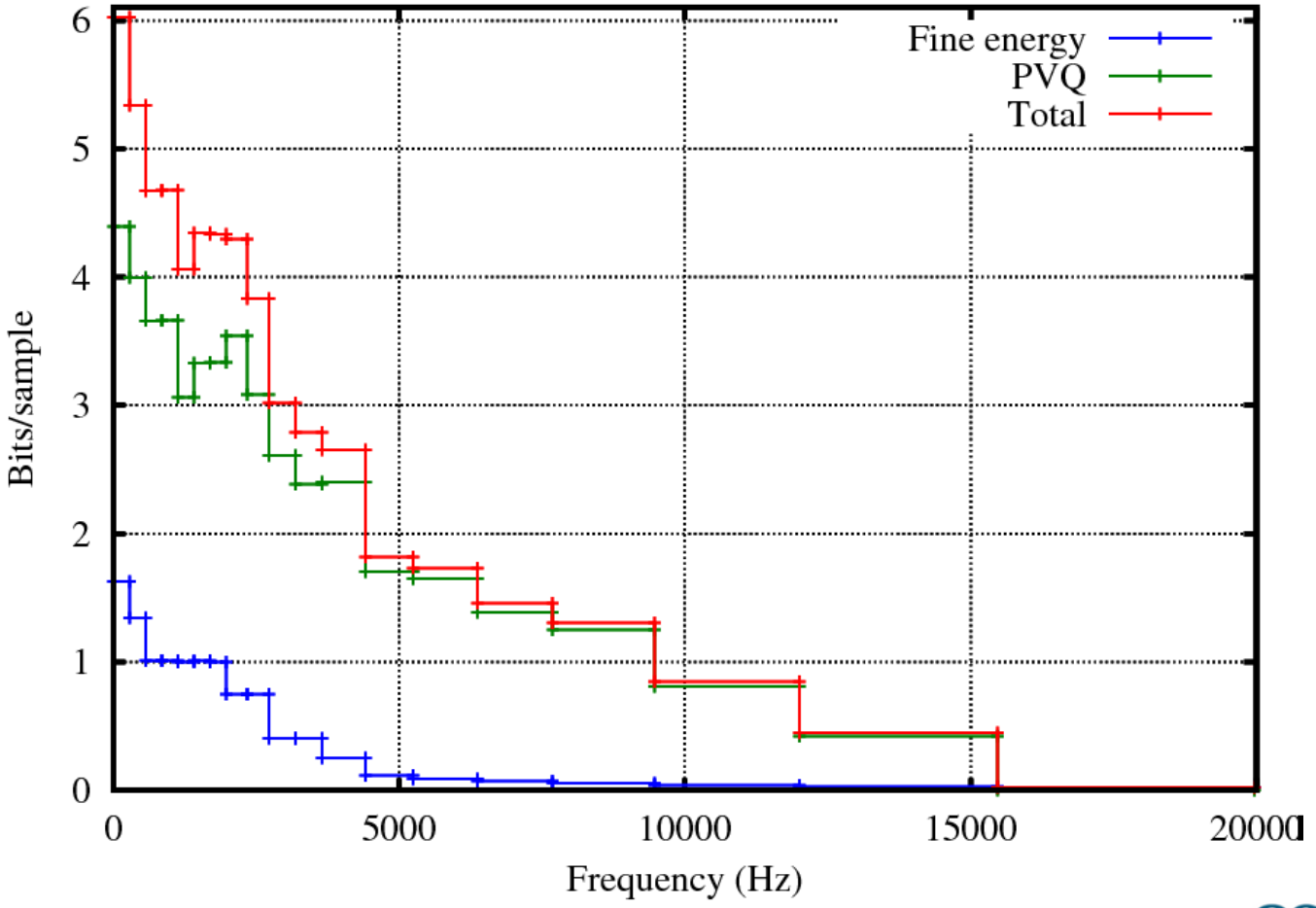
Perceptual Improvements

- **Pre-echo control**
  - Multiple smaller MDCTs, interleaved spectra
  - Energy computed as if a single MDCT
- **“Birdie” avoidance**
  - Adding an “offset” to PVQ quantization
  - Based on lower part of the spectrum
  - Gain = $N / (N + 6K)$

Bit Allocation

- **Fundamentally a CBR codec (VBR supported)**
- **Synchronized allocator in encoder and decoder**
  - Allocates fine energy bits and PVQ bits
  - Depends only on shared information
    - Number of compressed bytes
    - Number of bits used so far by the range coder
  - Near-constant bits per band in time
    - Models within-band masking with near-constant SMR
    - Does not model inter-band masking, tone vs noise
  - Implicit psycho-acoustic model (not coded)

Allocation Example (64 kb/s)

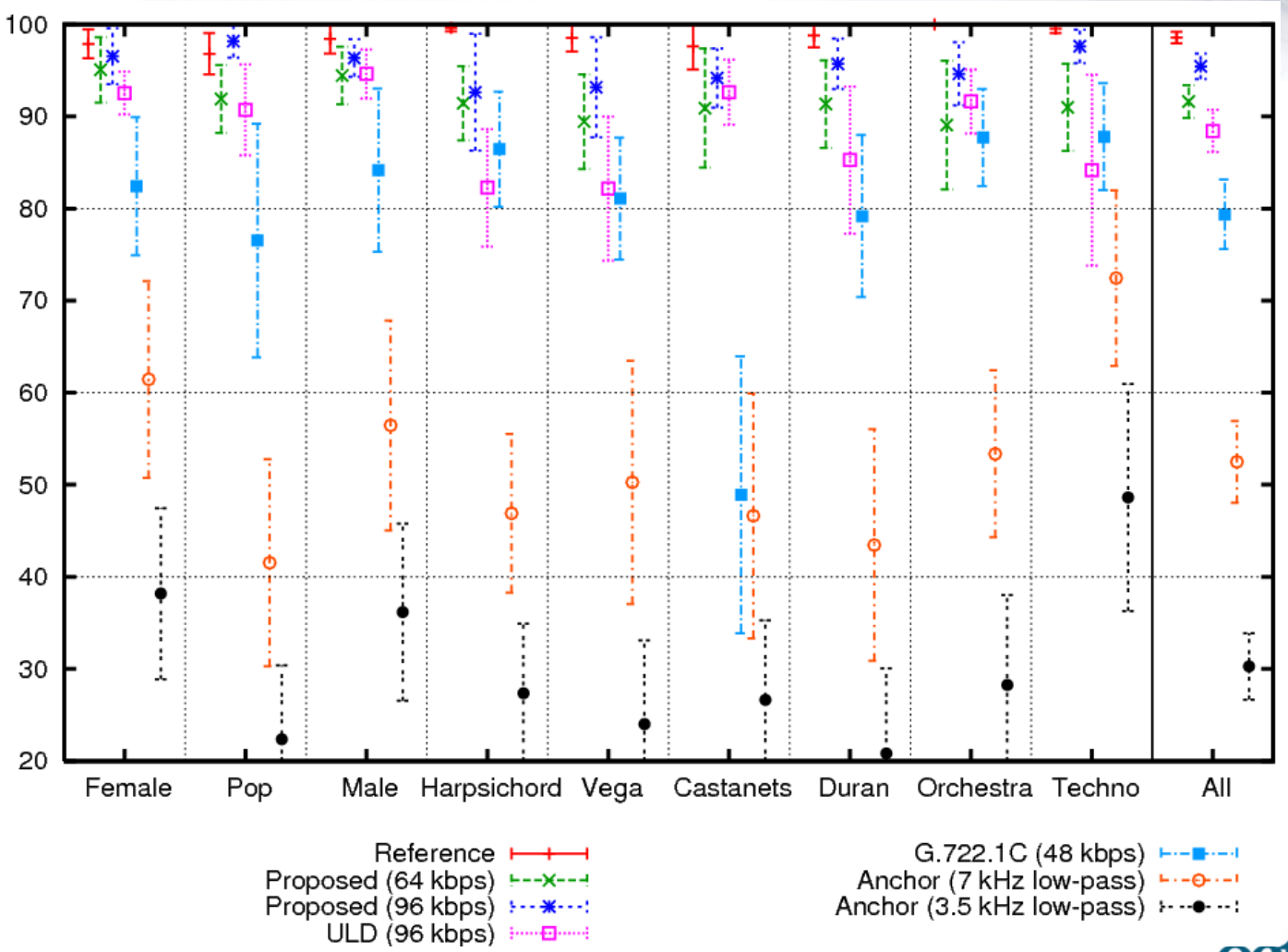


Evaluation

- **MUSHRA listening tests (10 listeners)**
  - CELT version 0.5.0 (proposed)
  - FhG ULD: warped LPC, pre-filtering
  - G.722.1C: MDCT, scalar quantization, uniform bands

Codec	Sample rate kHz	Bitrate kbit/s	Frame size sample (ms)	Look-ahead sample (ms)	**Total delay** sample (**ms**)
Proposed (64)	48	64	256 (5.3)	128 (2.7)	384 (**8**)
Proposed (96)	48	96	128 (2.7)	64 (1.3)	192 (**4**)
ULD	48	96	128 (2.7)	128 (2.7)	256 (**5.3**)
G.722.1C	32	48	640 (20)	640 (20)	1280 (**40**)

Results



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Complexity and RAM

- **Complexity (encoder+decoder average)**
  - 17 WMOPS in fixed-point
  - 27 MHz on Intel Core2 (unoptimised floating-point C)
- **State data (per channel)**
  - Encoder: 0.5 kB
  - Decoder: 0.5 kB (+ 4 kB for PLC)
- **Scratch space**
  - Encoder+decoder: ~7 kB

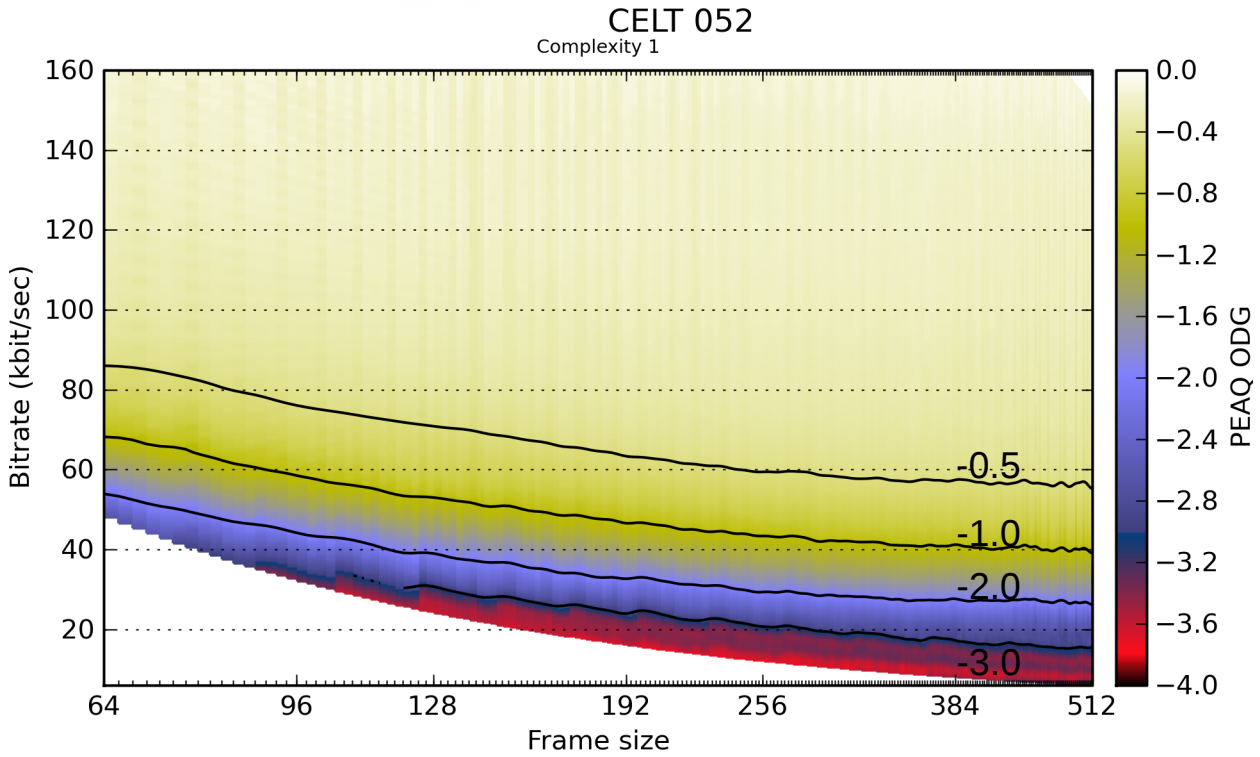
Conclusion

- **Low-delay coded, explicit energy constraint**
- **Work in progress**
  - Pitch prediction
  - Stereo coupling
- **Submitted to IETF as Internet codec proposal**
- **Resources**
  - Source code: http://www.celt-codec.org
  - Mailing list: celt-dev@xiph.org

Questions?

Ask me for audio samples after the session

Other Frame Sizes



Overhead is about 42 bits/frame