Improved Noise Weighting in CELP Coding of Speech

Applying the Vorbis Psychoacoustic Model To Speex

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Introduction

- Goal: Improve perceptual weighting of the noise in an existing CELP codec (Speex)
- Proposed solution: adapt and apply the Vorbis psychoacoustic model to the Speex codec
- Outline
  - Overview of Speex
  - Overview of Vorbis and psychoacoustic model
  - Application to Speex
  - Evaluation & results
  - Complexity
  - Conclusion

Overview of Speex

- Speech codec based on CELP
- Sampling rates, bitrates:
  - Narrowband (8 kHz): 2.15 kbps to 24.6 kbps
  - Wideband (16 kHz): 3.95 kbps to 42.2 kbps
- Features:
  - Open-source (BSD-licensed): http://www.speex.org/
  - Source-controlled variable bitrate (VBR)
  - Embedded wideband coding
  - Variable encoder complexity
  - Optimised for VoIP
- Bit-stream finalized in March 2003

Speex Encoder Structure

- CELP variant with
  - 20 ms frames (5 ms sub-frames)
  - No inter-frame coding other than LPC and pitch prediction
  - 3-tap pitch predictor
  - Sub-vector quantization of innovation
  - “Global” excitation gain
- Default noise weighting is LPC-derived

$$W(z) = \frac{A(z/\gamma_1)}{A(z/\gamma_2)}, \gamma_1 = 0.9, \gamma_2 = 0.6$$

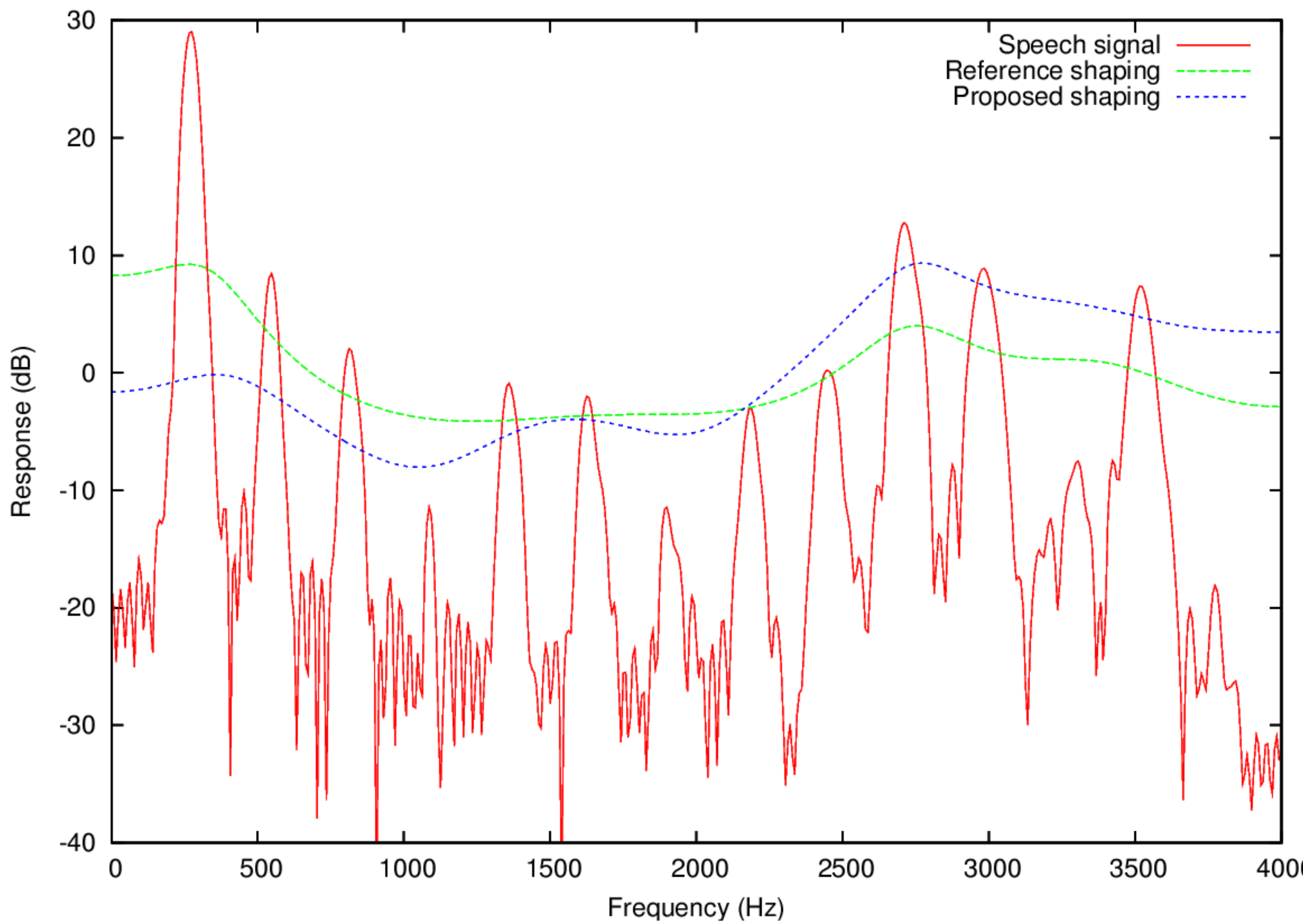
Vorbis Psychoacoustic Model

- Vorbis is an open-source, MDCT-based audio codec
- Psychoacoustic model shapes noise according to:
  - Tone masking
  - Noise masking
  - Noise normalization
  - Impulse analysis
- Noise shaping approximates the masking threshold
  - Good for transparent audio
  - Bad for lossy speech

Application to Noise Weighting in Speex

- Vorbis "floor" curve interpreted as the inverse of the optimal perceptual weighting filter
  - Amplitude companding required
- Compute curve for each frame and interpolate on sub-frames
- Convert to pole-zero model: $\frac{1}{W(z)} = \frac{W_n(z)}{W_d(z)}$
  - Denominator:
    - Curve to auto-correlation (IFFT)
    - Auto-correlation to LPC (Levinson-Durbin)
  - Numerator:
    - Remove denominator contribution (1/FFT of denominator)
    - Convert inverse to LPC (IFFT and Levinson-Durbin)

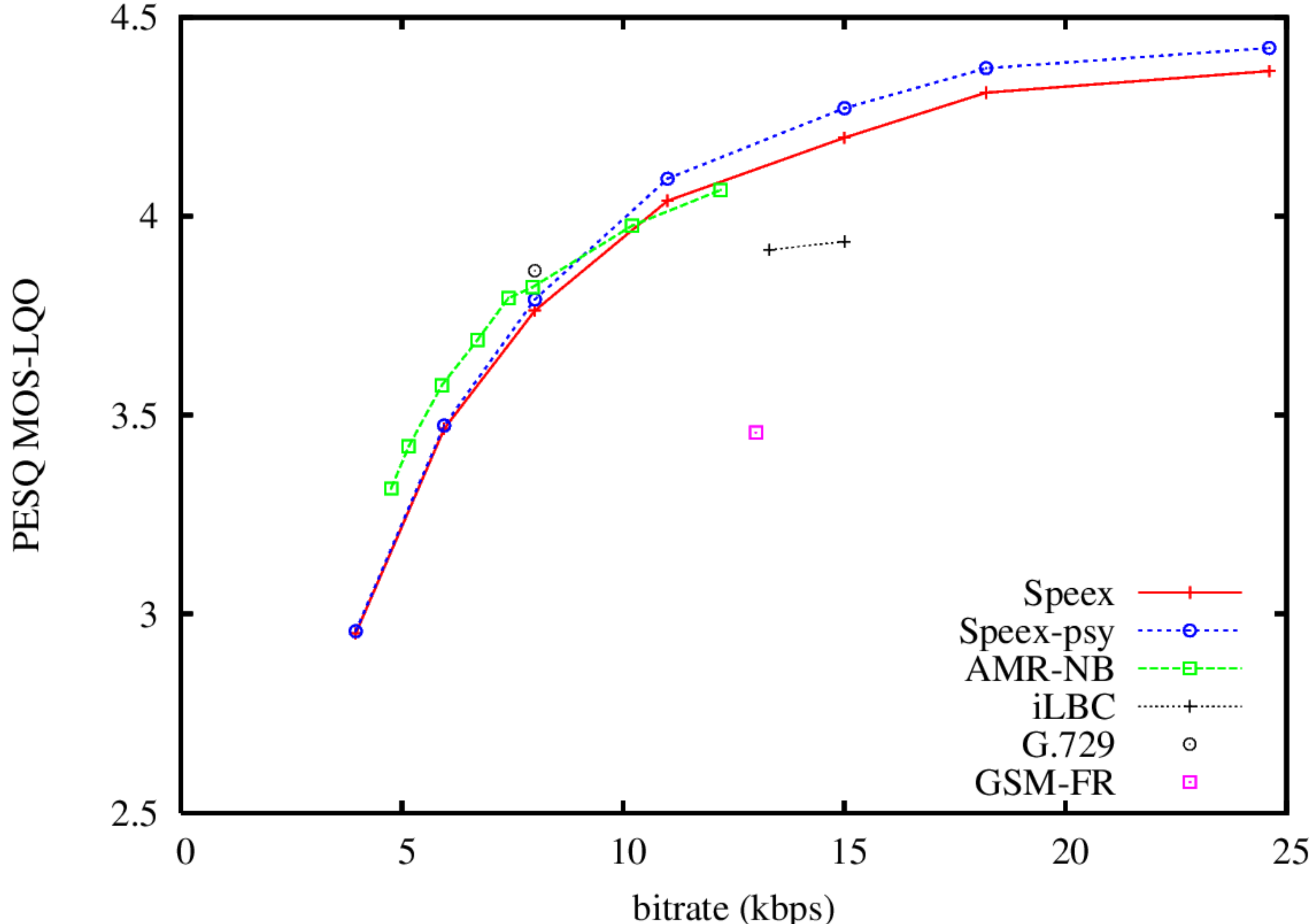
Curves


Speech signal
Reference shaping
Proposed shaping
Response (dB)
Frequency (Hz)
30
20
10
0
-10
-20
-30
-40
0
500
1000
1500
2000
2500
3000
3500
4000

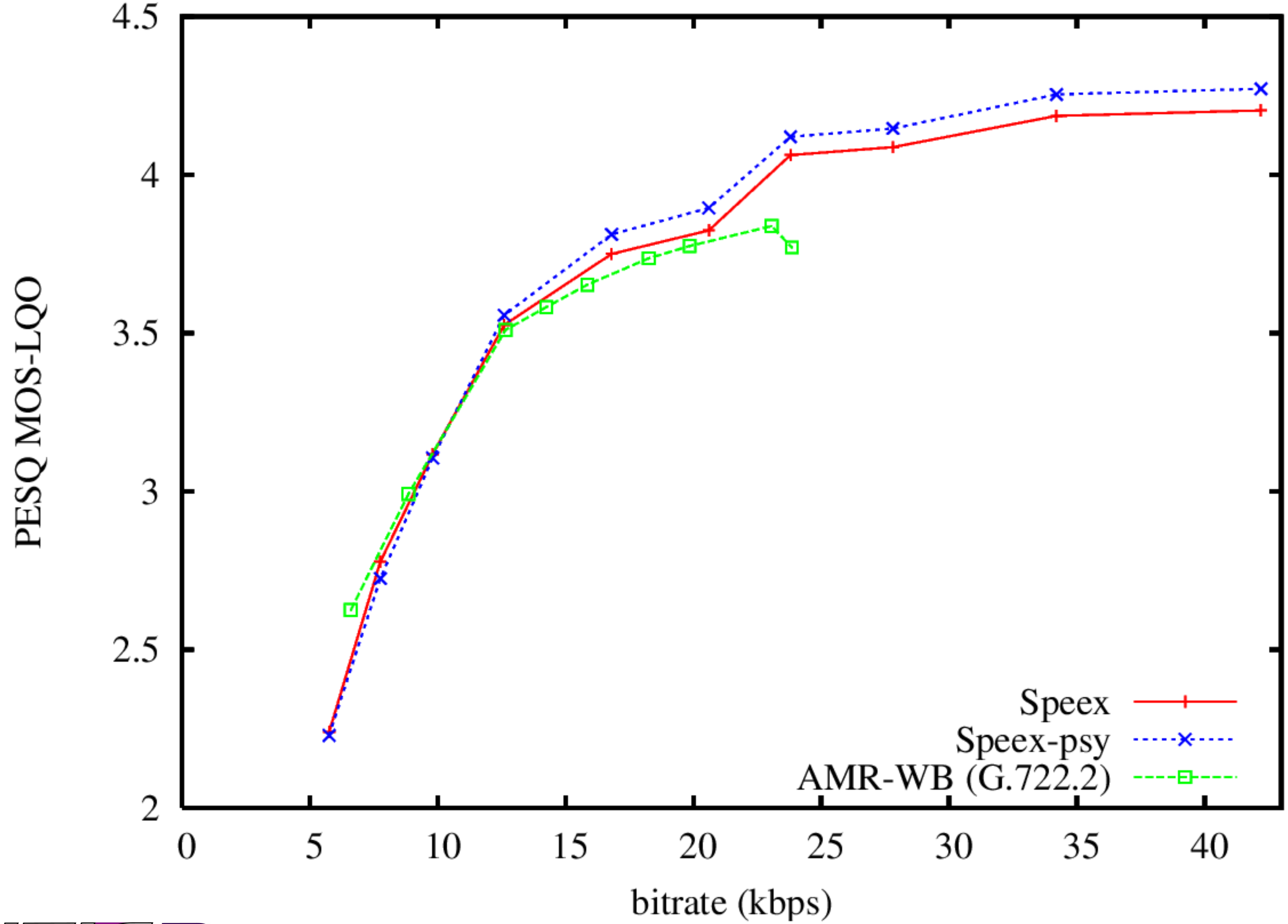
Evaluation

- Objective listening quality: PESQ MOS-LQ0 (P.862.x)
- Tested on NTT multilingual speech database
  - 354 files
  - 177 speakers
  - 20 languages
- Reference: Speex version 1.2-beta1 (pre-release)

Results (narrowband)



Results (wideband)



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Complexity Reduction

Three strategies:

1) Use all-pole model $\frac{1}{W(z)} = \frac{1}{W_d(z)}$

2) Force $W_d(z) = A(z)$

- Synthesis+weighting filter simplifies to $\frac{W(z)}{A(z)} = \frac{1}{W_n(z)}$
- Reduces complexity of the filtering

3) Apply 2) and make $W_n(z)$ constant for a whole frame

- Only one conversion per frame

None of 1), 2) or 3) causes significant degradation

Conclusion

- Proposed an improved noise weighting for the Speex codec
- Noise weighting is based on the Vorbis psychoacoustic model
- Up to 20% (equivalent) improvement at high bitrate
- Little or no improvement at low bitrate
- **A case for more research to be done in noise weighting for CELP**
- A subjective MOS test is desirable
- Future work
  - Investigate efficient approximations for $W_n(z)$
  - Derive CELP-specific masking models

Questions?