Rate-Constrained Beamforming with Application to Hearing Aids

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TAM, November 30, 2006
Outline

1. Motivations
2. The Rate-Constrained Hearing Aid Problem
3. Remote Source Coding with Side Information
4. Gain-Rate Analysis
5. Conclusions
Motivations (1/4)

Generalities

- Battery-operated sensing devices
- Types: behind-the-ear (BTE), in-the-ear (ITE), in-the-canal (ITC) and completely-in-the-canal (CTC)

- Analog vs. digital
- 1 to 3 (omni-)directional microphones, 1 loudspeaker
Goals

- Overcome user's hearing impairment
- Noise reduction
- Improve speech intelligibility
- ...

Motivations (2/4)
Motivations (3/4)

How to achieve these goals?

- Spectral shaping
- Beamforming

**Figure:** Example of beampattern at $f = 1000$ [Hz] for 2 microphones separated by $d = 0.2$ [m].
Assistive listening devices

Figure: Assistive listening devices. (a) Remote microphone. (b) Collaborating hearing aids.
Motivations (4/4)

- Assistive listening devices

**Figure:** Assistive listening devices. (a) Remote microphone. (b) Collaborating hearing aids.

**Fundamental gain-rate tradeoff**
Head-related configuration
Local perspective

\[ X_1 \xrightarrow{R_1} \hat{S}_1 \xrightarrow{} X_2 \]

Dec 1

Enc 2
Local perspective

\[ X_1 \quad \text{Enc 1} \quad X_2 \]

\[ R_2 \quad \hat{S}_2 \]

\[ \text{Dec 2} \]
Global perspective

\[ X_1 \]

\[ \hat{S}_1 \]

\[ \hat{S}_2 \]

\[ X_2 \]

\[ R_1 \]

\[ R_2 \]

Enc 1

Dec 1

Enc 2

Dec 2
Two classes of coding strategies

- **Side-information-aware (SIA) coding:**

  ![Diagram of SIA coding]

- **Side-information-unaware (SIU) coding:**

  ![Diagram of SIU coding]
Local perspective

- Gain-rate functions

**Figure:** Typical gain-rate function with SIA coding (plain) and SIU coding (dashed).
Local perspective

- Gain-rate functions

**Figure:** Typical gain-rate functions. (a) SIA coding. (b) SIU coding.
Local perspective

- **Gain-rate functions**

**Figure:** Gain-rate functions with SIA coding. (a) $\alpha_I = 5, 8, 10$ [deg] (bottom to top). (b) $d = 0.2$ [m] (plain) and $d = 0.02$ [m] (dashed).
Local perspective

- Optimal rate allocation across frequencies

**Figure:** Reverse “water-filling” power spectral density with SIA coding (plain) and SIU coding (dashed).
Gain-Rate Analysis (5/7)

Local perspective

- Rate-constrained directivity patterns (RCDP)

Figure: Typical RCDP with SIA coding (plain) and SIU coding (dashed) at $f = 2000$ [Hz] with $d = 0.2$ [m]. (a) $R_1 = 0.1$ [b/s/Hz] and (b) $R_1 = 1$ [b/s/Hz].
Global Perspective

- Optimal rate allocation between the hearing devices

**Figure:** Rate allocation benefitting to hearing aid 1 with SIA coding (plain) and with SIU coding (dashed) for different SNRs.
Also ...

- Head-shadow effect
- Perceptual weighting operator
- PSDs from speech excerpts
Conclusions

To conclude

- Identification of the problem
- Local & global perspectives
- Gain-rate characterization for SIA and SIU coding
- Optimal rate allocation policies
- Numerical results
Questions ?