Distributed Compression in Acoustic Sensor Networks Using Oversampled A/D Conversion

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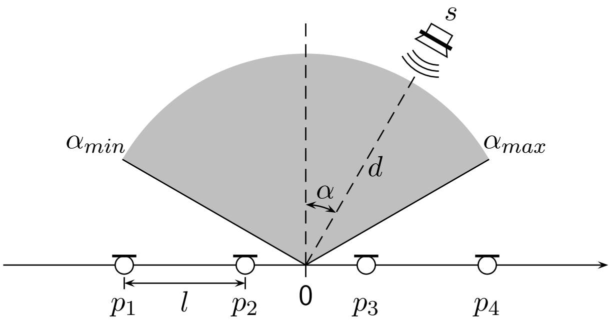
ICASSP, Toulouse - May 19, 2006

Outline

Problem statement (1/2)

- Sensor array configuration (here with $M = 4$ microphones):

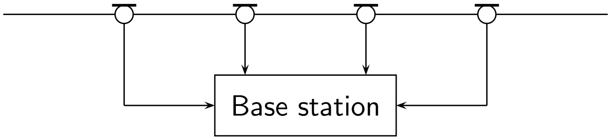


where $[\alpha_{min}, \alpha_{max}] \subset [-\pi/2, \pi/2]$

- Plenacoustic sampling (Ajdler *et al.*, [ASV06])

Problem statement (2/2)

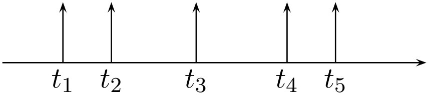
- Goal: efficiently transmit the acquired signals to a central base station for processing (e.g. time-delay estimation, beamforming, tracking)



- Assumptions:
  - Parameters known at the sensors and the central base station
  - Far-field (plane-wave with constant attenuation factor)
  - Only quantization noise is taken into account

Our coding scheme for synthetic sources (1/5)

- Synthetic sources made of K dirac with unit weight and time position t_k $(k = 1, 2, \ldots, K)$



- Time of arrival (TOA) of the k-th dirac at microphone m:

$$t_{k,m} = t_k + \tau_m = t_k + \frac{d - p_m \sin \alpha}{c}$$

Our coding scheme for synthetic sources (2/5)

- Observation interval $[0, T)$ divided into n bins of duration $T_s = T/n$ seconds
- The TOA's are quantized as

$$b_{k,m} = \lfloor t_{k,m}/T_s \rfloor$$

  and transmitted using $B = \lceil \log_2(n) \rceil$ bits
- Overall transmission rate is $R = MKB/T$ bits per second

Our coding scheme for synthetic sources (3/5)

- Key idea: geometrical properties of the setup can be used to further reduce the bit-rate
- For two consecutive microphones (say microphone 1 and 2):

$$b_{k,2} - b_{k,1} \in \left[-\left\lceil \frac{l \sin \alpha_{max}}{T_s c} \right\rceil, -\left\lfloor \frac{l \sin \alpha_{min}}{T_s c} \right\rfloor \right]$$

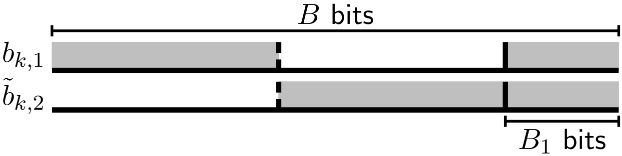
- The difference (if available) can thus be coded using

$$B_1 = \lceil \log_2(\delta + 1) \rceil \quad \text{bits}$$

where $\delta = \lceil (l \sin \alpha_{max})/(T_s c) \rceil - \lfloor (l \sin \alpha_{min})/(T_s c) \rfloor$

Our coding scheme for synthetic sources (4/5)

- Problem: the difference $b_{k,2} - b_{k,1}$ is not available at the microphones
- We use the coding technique devised by Gehrig and Dragotti in the context of the plenoptic function [GD04]:

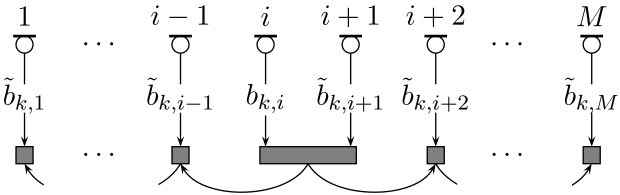


where $\tilde{b}_{k,2} = b_{k,2} + \lceil (l \sin \alpha_{max})/(T_s c) \rceil$

- Total number of bits: $B + B_1$ (the same as if the difference $b_{k,2} - b_{k,1}$ were available)

Our coding scheme for synthetic sources (5/5)

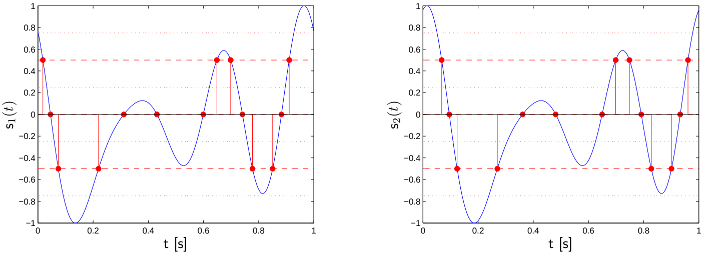
- Extension to $M > 2$ microphones:



- Gain: $G = K(M-1)(B - B_1)/T$ bits per second
- Better source localization allows to lower the transmission rate: iterative algorithm with feedback from the base station

Our coding scheme for periodic bandlimited signals (1/5)

- How to apply these insights to periodic bandlimited signals?
  $\Rightarrow$ Oversampled A/D conversion
- For small enough T_s, the signal is completely determined by its quantization threshold crossings (QTC) [TV94]

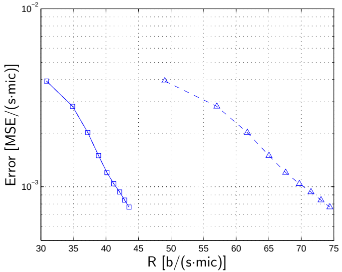


Our coding scheme for periodic bandlimited signals (2/5)

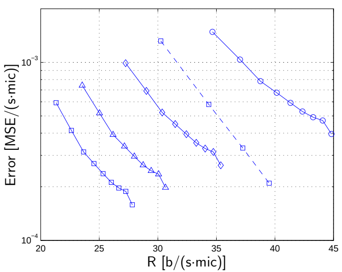
- Coding scheme (oversampled A/D conversion):
  - We encode the QTC's time positions using the method for synthetic signals
  - Each QTC level is encoded by only one microphone
  - A consistent reconstruction algorithm is applied at the base station

Our coding scheme for periodic bandlimited signals (3/5)

- Simulation results ($\alpha_{max} = -\alpha_{min} = 90$ [deg]):



(a)

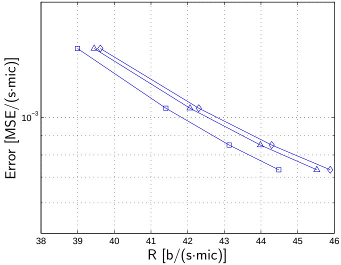


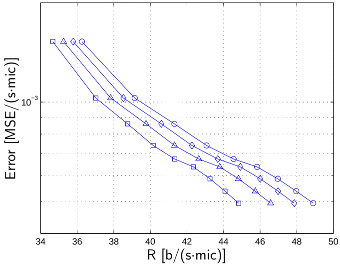
(b)

(a) Oversampled A/D conversion with (solid) and without (dashed) geometrical considerations for $M = 2$ microphones
(b) Simple A/D conversion (dashed) and our distributed coding scheme (solid) for $M \in \{2, 3, 4, 5\}$ (from right to left)

Our coding scheme for periodic bandlimited signals (4/5)

- Simulation results ($M = 2$):





(a) $\alpha_{max} = -\alpha_{min} \in \{10, 50, 90\}$ [deg] (left to right)
(b) $l \in \{0.5, 1, 1.5, 2\}$ [m] (left to right)

Our coding scheme for periodic bandlimited signals (5/5)

- How to apply these insights to periodic bandlimited signals?
  $\Rightarrow$ Fourier expansion
- Coding scheme (Fourier expansion):
  - The phase of every Fourier coefficient is quantized and encoded using the method for synthetic signals
  - The magnitude is encoded by only one microphone

Conclusions

- Distributed compression in acoustic sensor networks for a simple scenario
- Distributed coding scheme that exploits the geometrical properties of the array
- Efficient use of oversampled A/D conversion in this context

References

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