Proposal #516

Task-Based Quantization for Multi-user Signal Recovery Demo

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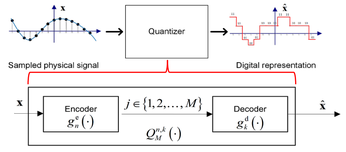
Motivation and Contributions

- Quantization plays a critical role in digital signal processing systems
- Conventional ADCs suffer from severe cost, power consumption, and memory burden
- The proposed task-based quantization approach achieves good performance from a low-bit representation by exploiting the underlying task in designing the quantization system
- We implement signal recovery of two users, achieving a reduction of ~25 in memory by reducing from 16 receivers with 16 bits each to 2 receivers with 5 bits each, without compromising performance
- Analog precoding is used prior to quantization

Quantizer

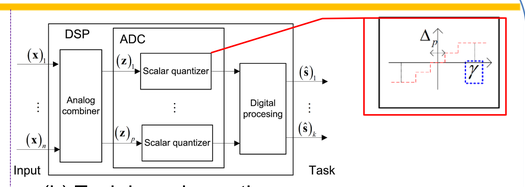


(a) Conventional quantizer

- A quantizer consists of Encoder (analog→bits) and Decoder (bits →digital representation)
- Performance measures:

  Quantization rate $R = \frac{1}{n}\log M$

  Expected distortion $D = E\{\|\boldsymbol{x} - \hat{\boldsymbol{x}}\|^2\}$



(b) Task-based quantizer

- Simple scalar ADCs + Analog combiner
- Jointly optimize the combiner and the ADCs based on the task
- Task dimension (k) ≤ input dimension (n)

Problem Formulation

- For the task of multi-user signal recovery, we have $N = 16$ antennas at the receiver to recover transmitted signals $\boldsymbol{s}$ from $K = 2$ users. The received signal $\mathbf{y}$ is expressed as:

$$\boldsymbol{y} = \mathbf{H}\boldsymbol{s} + \boldsymbol{v}$$

  where $\mathbf{H}$ is the channel.

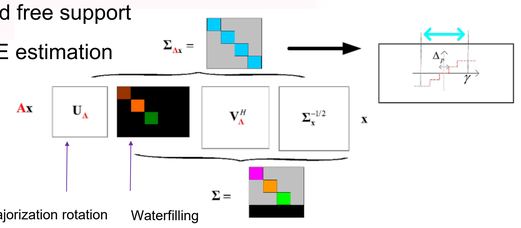
  The following task-based quantization processing is employed:
- Analog processing: $\boldsymbol{z} = \boldsymbol{A}\mathbf{y}$, with $\boldsymbol{A} \in \mathcal{R}^{P\times N}$ denoting the analog combiner
- Quantization and digital processing: $\hat{\boldsymbol{s}} = \boldsymbol{B}\boldsymbol{Q}(\boldsymbol{z})$, where $\boldsymbol{Q}(\cdot)$ denotes the low-bit quantization operation, and $\boldsymbol{B} \in \mathcal{R}^{K\times N}$ denotes the digital combiner
- The recovery distortion:

$$D = E\{\|\boldsymbol{s} - \hat{\boldsymbol{s}}\|^2\}$$

Task-based Quantization Design

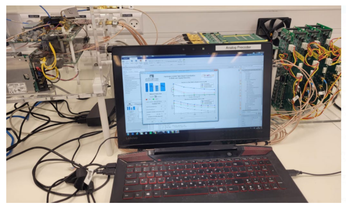
The optimal hardware-limited task-based quantizer includes[1]:

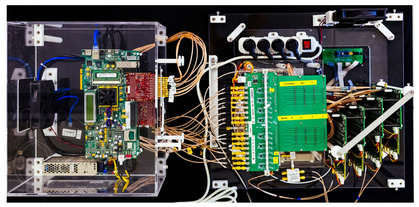
- Analog domain: “Waterfilling” + rotation
- Quantization: Overload free support
- Digital domain: MMSE estimation



[1] N. Shlezinger, Y. C. Eldar, and M. R. Rodrigues, “Hardware-limited task-based quantization,” IEEE Trans. Signal Process., vol. 67, no. 20, pp. 5223–5238, 2019.

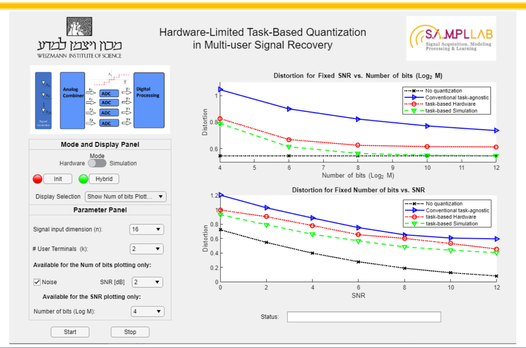
Hardware



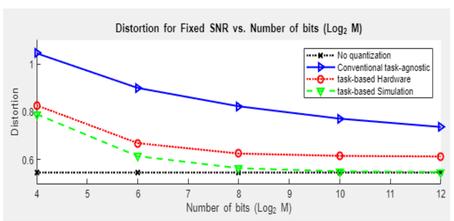


Parameters	Value
Carrier frequency	$f_c = 2.3$ GHz
Baseband bandwidth	$BW = 50$ MHz
DAC	2 channels, each 250 MSPS
ADC	2 channels, each $f_s = 250$MHz

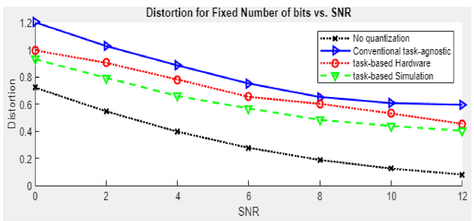
User Interface



Results



(a)



(b)

- We evaluate the achievable MSE in multi-user signal recovery, using the developed hardware prototype. Figs (a) and (b) show the MSE distortion with respect to different number of bits and SNRs, respectively
- From Figs (a) and (b), it can be observed that the proposed task-based low bit quantizer approaches the optimal performance as the quantization bit M increases
- When each scalar quantizer uses at least five bits, i.e., $\log(\mathrm{M})\geq 5\mathrm{K}$, the quantization error becomes negligible
- Hardware results agree with simulation