McGill
Department of Electrical and Computer Engineering

Low-Delay Joint Source-Channel Coding with Side Information at the Decoder

M. Vaezi

A. Combernoux

F. Labeau

Motivation and Applications

Limited delay is a key design constraint in modern practical applications. We lay a foundation for a low-delay distributed joint source-channel coding (DJSCC) system for delay-sensitive sensor networks over impulsive noise channel.

Applications:

- Substation monitoring using sensor networks
- Sensors networks interfered by urban or military radio

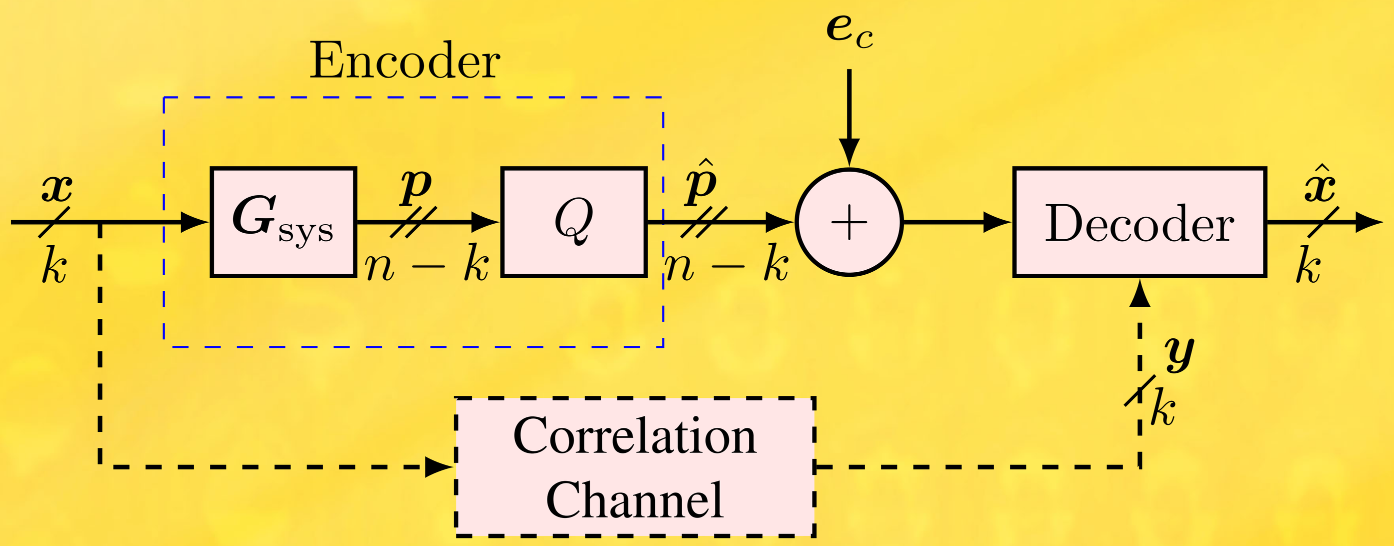
DSC: Different Approaches

Different approaches to distributed source coding (DSC):

1. *Quantization then binning:*
   (i.e., using binary codes)
   - Asymptotically optimal
   - Incurs excessive delay
   - Complexity is high
2. *Analog mapping:*
   - Zero delay
   - Low complexity
   - Far from theoretical limits
3. *Binning then quantization:*
   (i.e., using real-valued codes)
   - More accurate correlation model
   - Low complexity
   - Suitable for low-delay applications
   - Fits well for impulsive noise environment

DJSCC: The Proposed Scheme

We introduce JSCC with side information at the decoder based on *binning then quantization* approach.



Why JSCC?

- The *separation theorem* is optimal only asymptotically (infinite complexity and delay)
- JSCC (and DJSCC) can outperform separate coding in some practical cases

Encoding

Since binning is performed before quantization, we need real-number codes. We use discrete Fourier transform (DFT) codes, a class of BCH codes in the DFT domain.

Given an (n, k) systematic DFT code

- To compress and protect $\boldsymbol{x}$, the encoder generates and transmits **parity** sequence $\boldsymbol{p}$ of $n-k$ samples, with respect to the code
- Total compression ration is $\eta = \frac{k}{n-k}$ (for $n > 2k$ expansion happens)

Decoding

Let $\boldsymbol{e}_c$ and $\boldsymbol{e}_v$ represent the channel error and virtual correlation channel error. Then, neglecting quantization, received parity vector is given by: $\tilde{\boldsymbol{p}} = \boldsymbol{p} + \boldsymbol{e}_c$,
and, side information is equal to: $\boldsymbol{y} = \boldsymbol{x} + \boldsymbol{e}_v$

For decoding

- At the decoder, we form

$$\boldsymbol{z} = \begin{bmatrix} \boldsymbol{y} \\ \tilde{\boldsymbol{p}} \end{bmatrix} = \begin{bmatrix} \boldsymbol{x} \\ \boldsymbol{p} \end{bmatrix} + \begin{bmatrix} \boldsymbol{e}_v \\ \boldsymbol{e}_c \end{bmatrix} = \boldsymbol{G}_{\rm sys}\boldsymbol{x} + \boldsymbol{e},$$

  and, multiplying both sides by the parity-check matrix $\boldsymbol{H}$ to obtain the syndrome of error

$$\boldsymbol{s}_z = \boldsymbol{s}_e.$$

- Then, we apply syndrome decoding of BCH-DFT codes
- With quantization, we get

$$\boldsymbol{s}_z = \boldsymbol{s}_e + \boldsymbol{s}_q,$$

  in which $\boldsymbol{s}_q \equiv \boldsymbol{Hq}$ is the syndrome of quantization error

Other Contributions

In general, the decoding of DFT codes has three steps (detection, localization, correction). In this paper

1. We integrate subspace-base error localization, rather than coding theoretic approach, in the context of DSC and DJSCC
2. We improve the first step (error detection), which is applicable to channel coding as well

New detection:

Estimate the number of errors based on the eigenvalues of the syndrome matrix rater than its determinant. To do this, we fix a threshold for maximum eigenvalue when there is quantization error only (no channel errors) and we use that threshold during decoding.

Simulation Results

Simulations are carried out for Gauss-Markov source with mean 0, variance 1, and correlation coefficient 0.9.
Parity samples are generated using $(10, 5)$ DFT code, quantized with a 6-bit uniform quantizer, and transmitted over an impulsive noise channel.

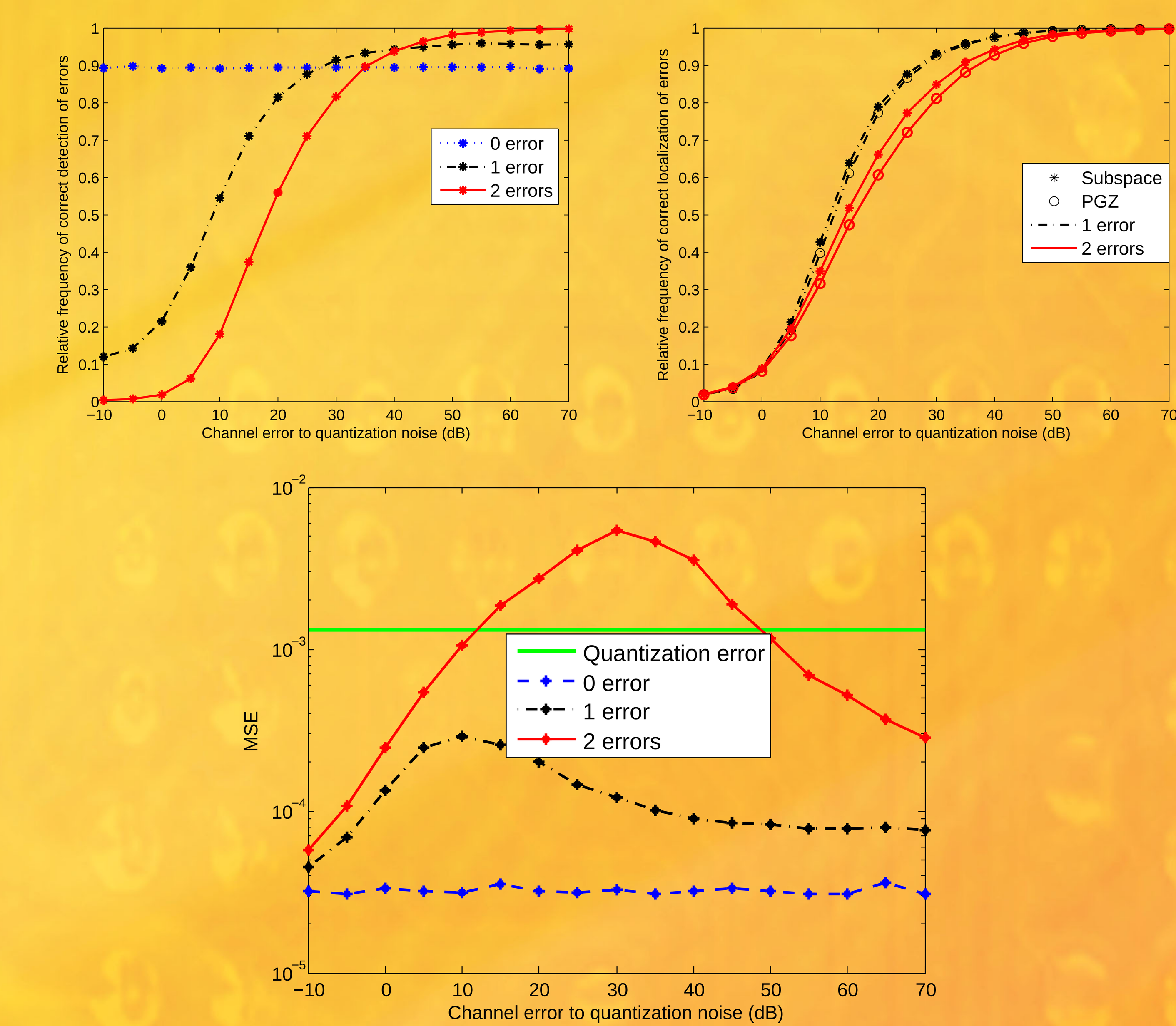


Figure: Error detection (top left), error localization (top right), and mean-squared reconstruction error (bottom) for DJSCC based on a (10, 5) DFT code.

- Even using a very short code we can achieve MSE which is better than the ideal case in *quantize and bin* approach, if no further estimation exist after Slepian-Wolf decoding
- Complexity of encoding and decoding is much less due to short block length and non-iterative decoding
- The performance improves with rate-adaptation

Conclusions and Future Work

We have studied a low-complexity, low-delay scheme for lossy JSCC with side information at the decoder which is suitable for impulsive noise environments.

Future work includes integrating subspace based decoding into more powerful iterative recovery algorithms, to further improve the decoding.

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