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Data compression in medical implants

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Outline

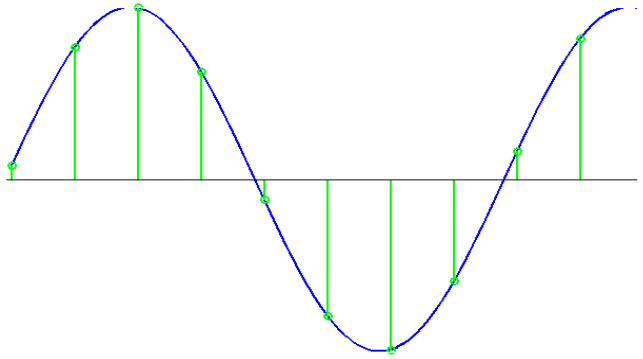
- Removal of temporal correlation: Differential pulse code modulation (DPCM)
- Example: ECG sinal processing with DPCM
- Exploring inter-sensor correlation: Distributed quantization (DQ)
- Example: Combining DPCM and DQ

Measuring physical processes

- Signals resulting from measurement of physical phenomenon are usually correlated
- Correlation in time: Compression with DPCM to reduce power consumption/rate
- Several sensors: exploit inter-sensor correlation with Distributed Quantization to reduce power/rate
- Combine schemes to exploit both temporal and inter-sensor correlation
- For implants: Crucial with low power consumption

Temporal correlation (one sensor)

- Correlation is redundant -> can be removed at encoder and added at decoder
- Remove redundancy (compression) prior to transmission -> reduced power consumption
- Compression scheme must be of low complexity to be effective
- DPCM: Removes correlation at low complexity



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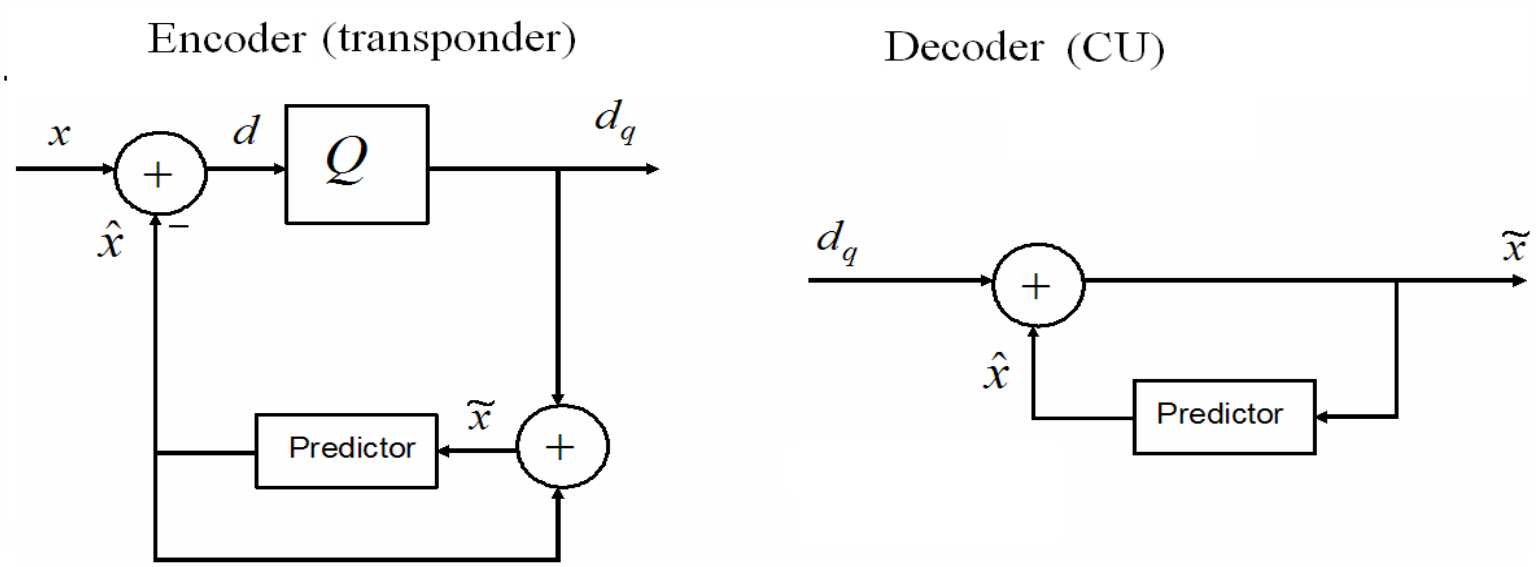
DPCM

- Exploits correlation by predicting current signal sample based on P previous samples
- Communicate prediction error
- Predictor: P'th order FIR filter



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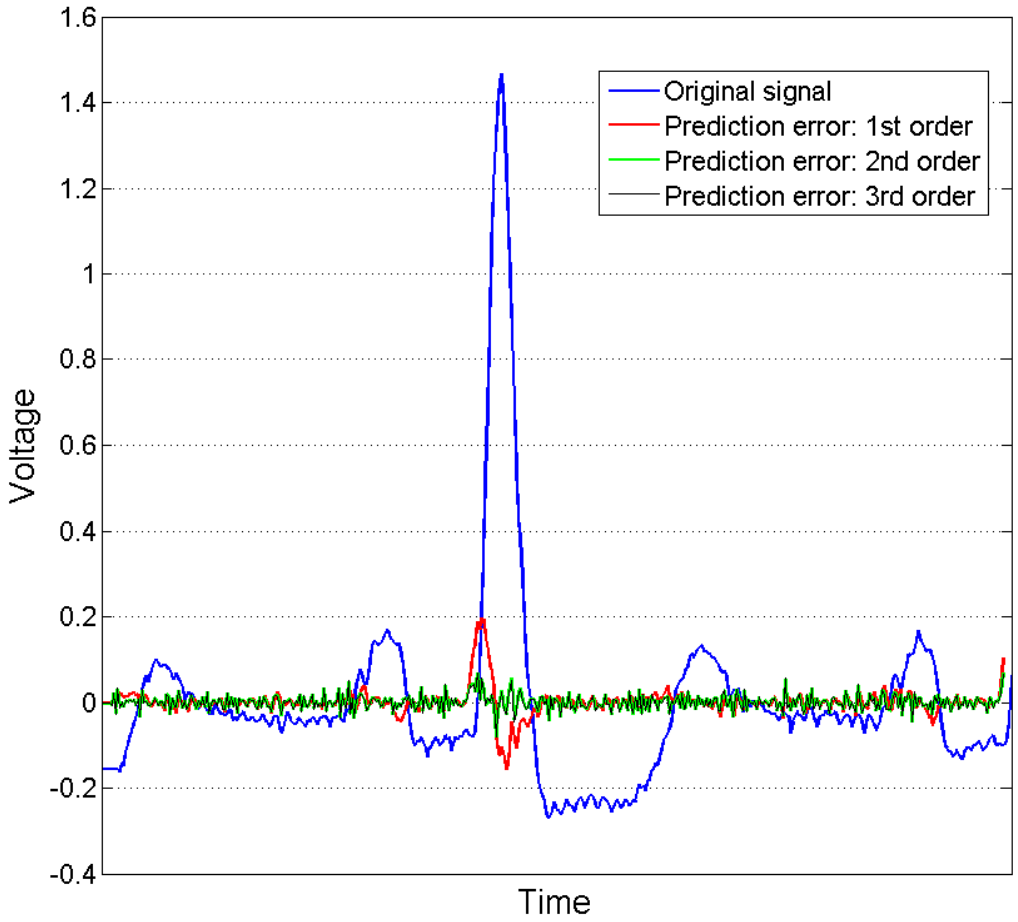
DPCM cont'd

- Predictor coefficients determined from relevant data.
- Stationary signal: Solve Yule-Walker equations:

$$\hat{R}\vec{c} = \sigma_d^2 \begin{bmatrix} 1 & 0 & \cdots & 0 \end{bmatrix}^T$$

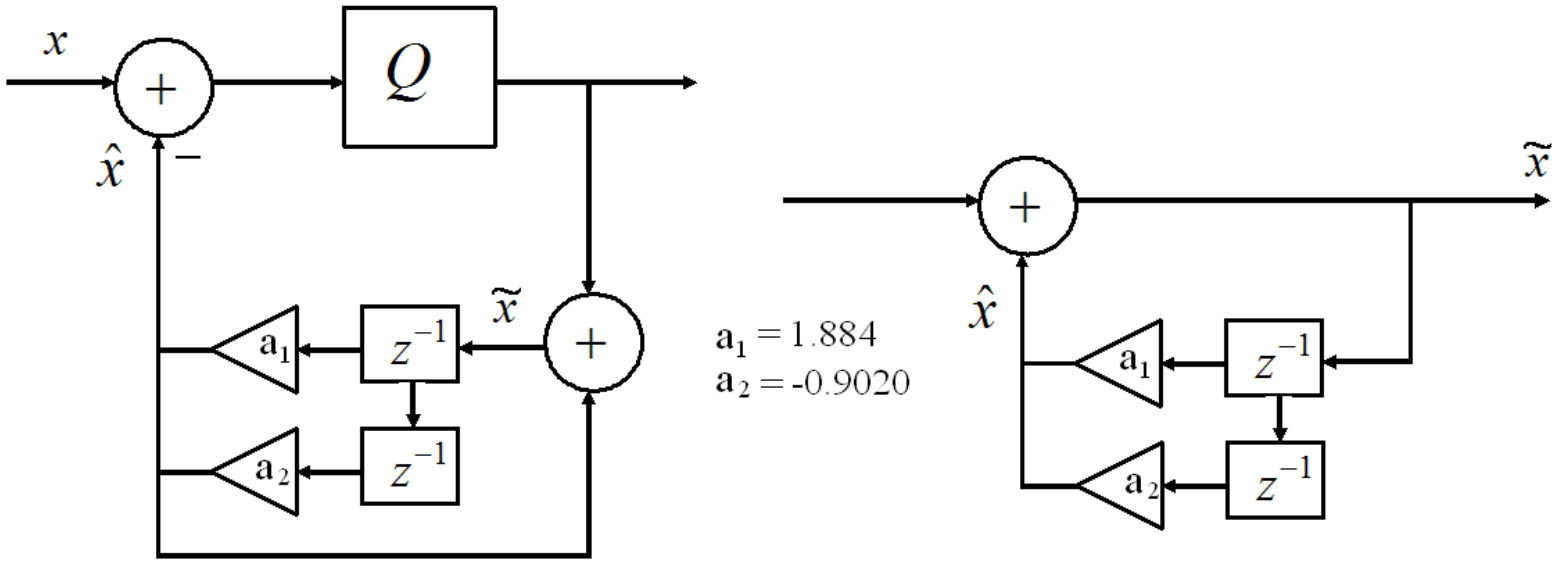
- $\vec{C}$ - coeficients. $\hat{R}$ - estimated correlation matrix from relevant data
- Non-stationary signal: Adapt coefficients with *Levinson Recursion*

Example: DPCM and ECG signal [1]

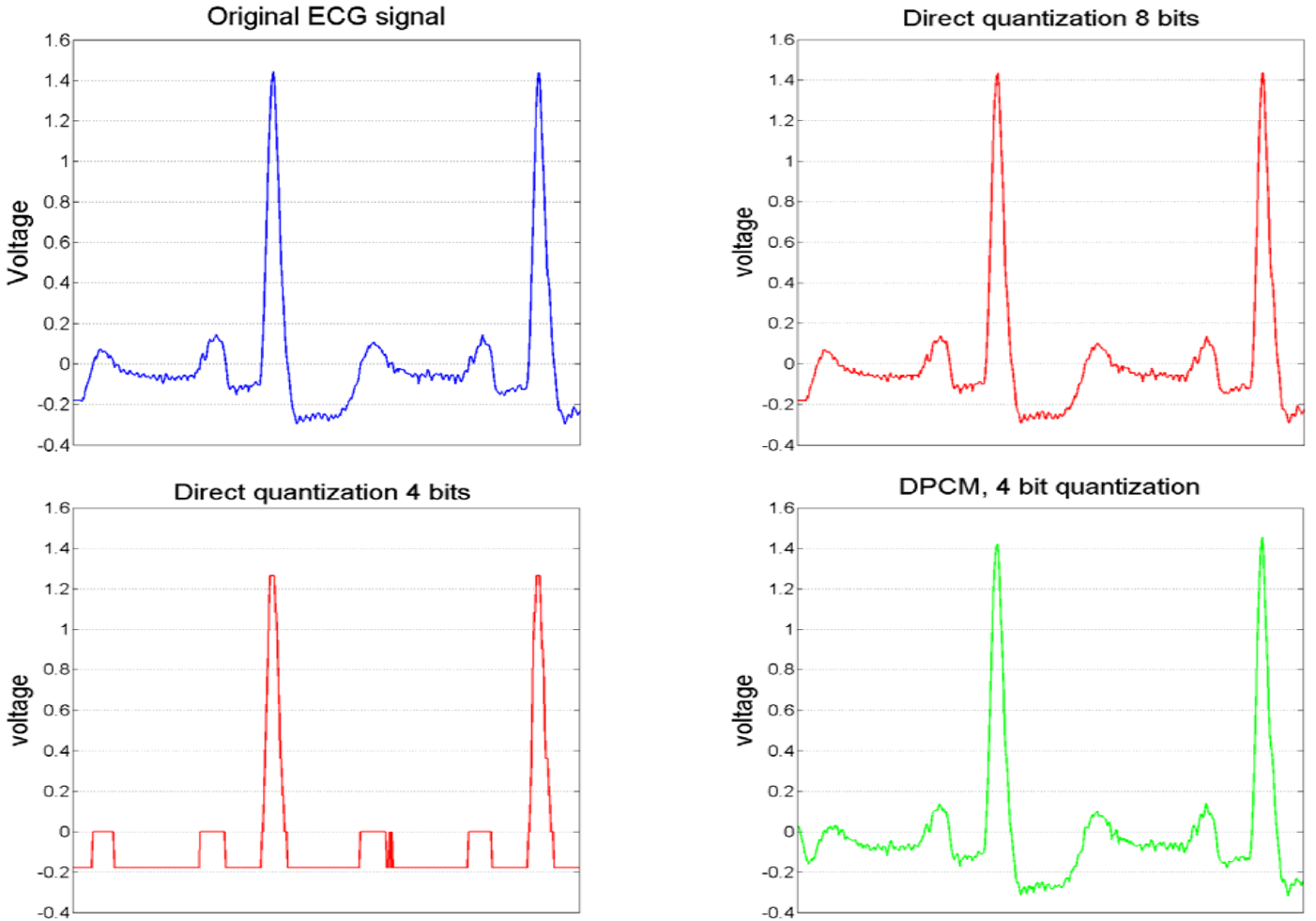


DPCM and ECG cont'd

- Power reduced ≈ 280 times with 2'nd order predictor
- Quantize prediction error instead of original!
- Low complexity:

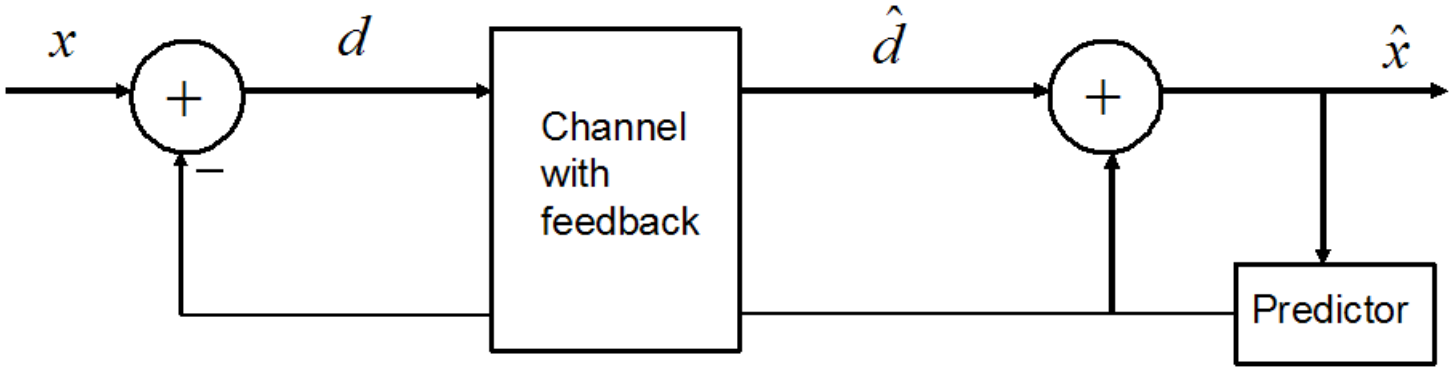


DPCM and ECG cont'd



With a good feedback channel

- Predictor can be moved to receiver (CU) [2]:



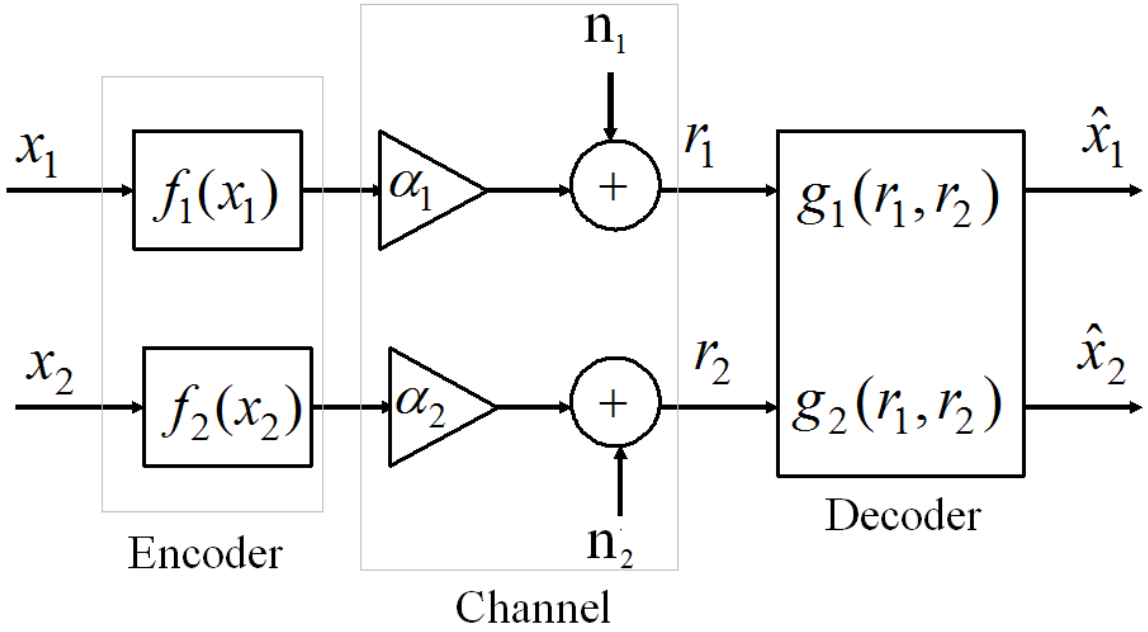
- Very simple encoder

Multi-user schemes

- Correlation between different sensors are exploited
- Can potentially achieve lower power consumtion per sensor
- Joint compression of several sources: Distributed Quantization
- Distributed: Since cooperation between implants is difficult

2-node sensor network

- Orthogonal transmission



- Best possible encoders and decoders?
- Optimal performance known for Gaussian case

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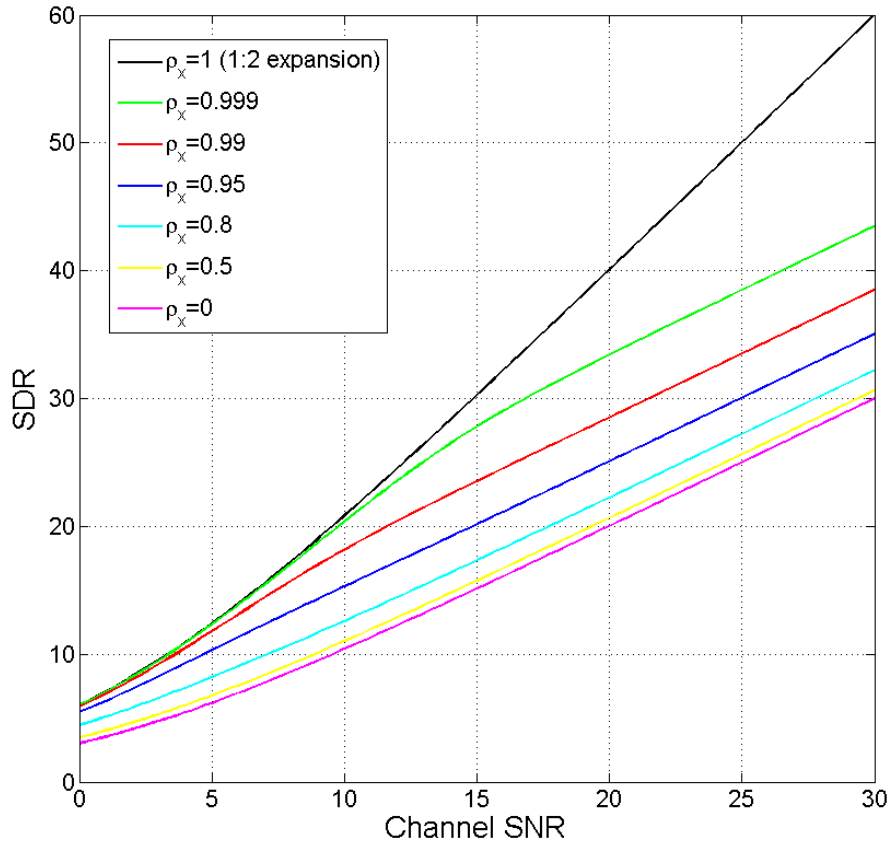
Gaussian sensor network (GSN)

- Optimal performance for $\alpha_1 = \alpha_2 = 1$ and correlation ρ_x



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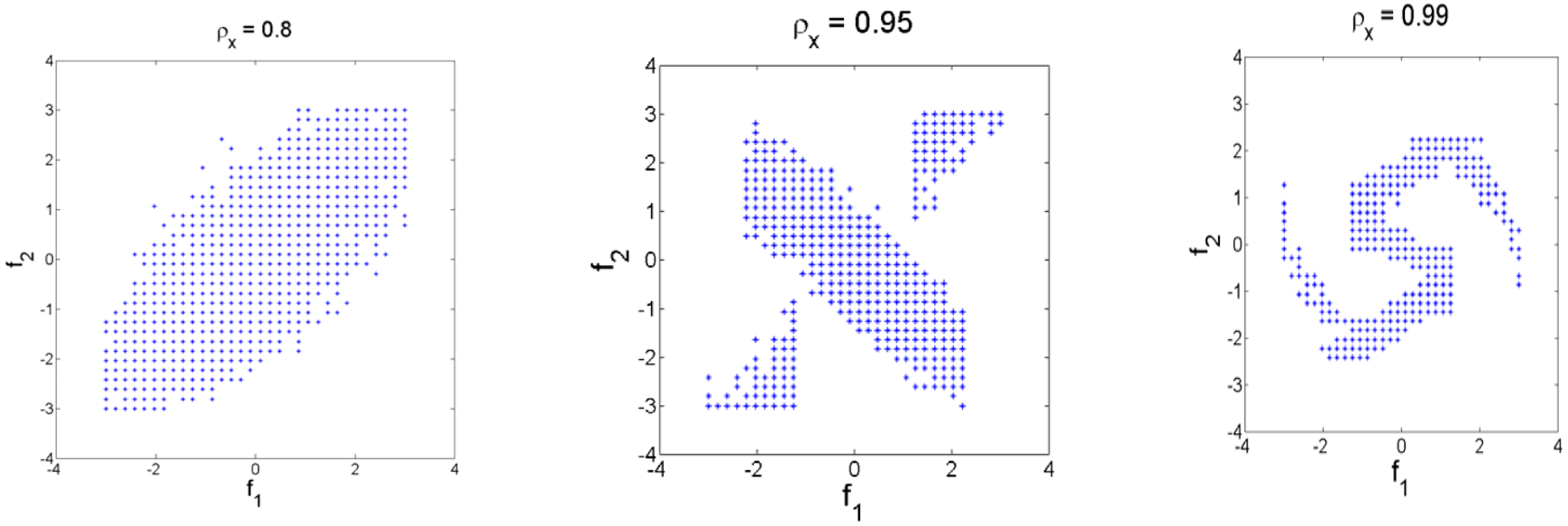
GSN cont'd

- Correlation must be very large to gain significantly from multiuser schemes
- Low correlation: Do not bother!
- High correlation: Worth exploring

Distributed Quantization

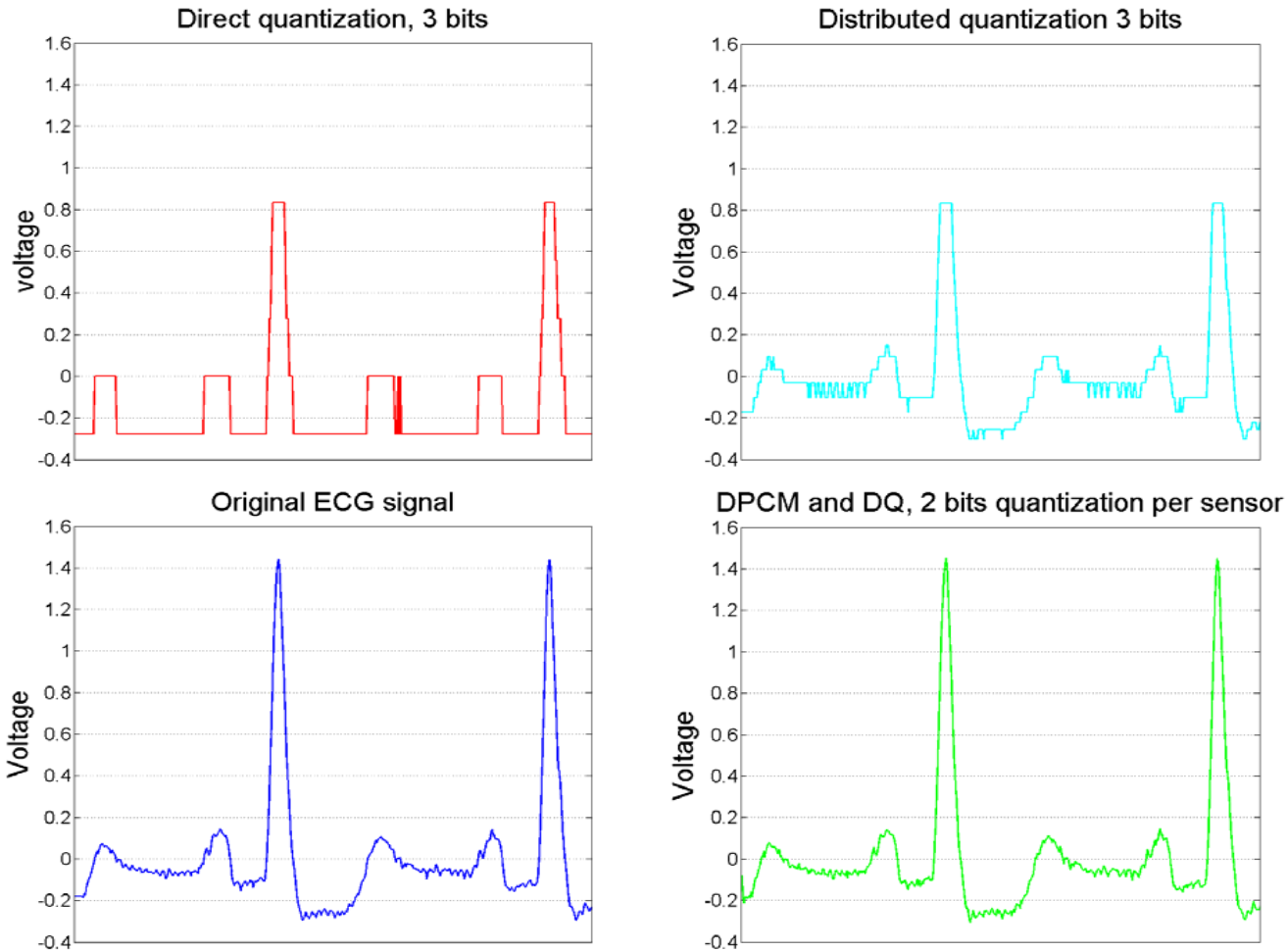
- Encoders: Co-optimized scalar quantizers [3]



- $\rho_x \in [0.95,1]$: Re-use of quantizer indices -> Better resolution for given number of bits

ECG processing: DQ and DPCM

$\rho_x \approx 0.999$



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Conclusion

- DPCM gives significant compression of correlated signals at low complexity
- Multiuser schemes only gives compression gain at high inter-sensor correlation
- Combining DPCM and DQ: small number of bits per sensor achieved
- Most potential lies in DPCM coding for each sensor

References

- [1]: S.M. Lalaleddine, C. G. Hutchens, R. D. Strattan, and W. A. Coberly. “ECG data compression techniques – a unified approach”. *IEEE Transactions on Biomedical Engineering.,* vol. 37, no. 4, pp. 329-342. April 1990.

- [2]: T. A. Ramstad, “Simple and reliable power image communication based on dpcm and multiple refinements through feedback,” in *3rd International Symposium on Communications, Control and Signal Processing.* IEEE, Mar. 2008.

- [3]: N. Wernersson, J. Karlsson, and M. Skoglund, “Distributed quantization over noisy channels,” *IEEE Transactions on Communications.,* vol. 57, no.6, pp. 1693-1700, June 2009.