Minimum Distortion Variance Concatenated Block Codes for Embedded Source Transmission

Suayb S. ARSLAN

Quantum Corporation

International Conference on Computing, Networking and Communications (ICNC), Feb 6, 2014, Honolulu, Hawaii/USA.

Outline

- Source quality assessment basics
- Progressive source compression
- Unequal Protection Schemes:
  - Conventional Schemes.
  - Previous work: Concatenated Block Coding
- Few results and issues about the previous work
- Description of the extension scheme (proposed)
  - Optimization of parameters
- Numerical results

Source quality assessment Basics: Image compression

- Given two images *I* and *I'* (original and the noisy version), the distortion will be measured by Mean Square Error (MSE):

$$MSE = \frac{1}{L_x \times L_y} \sum_{y=1}^{L_y} \sum_{x=1}^{L_x} [I(x,y) - I'(x,y)]^2$$

where L_x and L_y are dimensions of the image.

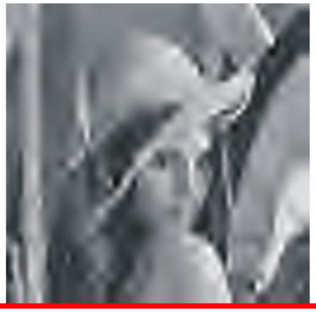
- Peak Signal to Noise Ratio (PSNR in dB) is defined to be

$$PSNR = 10 \times \log_{10}\left(\frac{I_{max}^2}{MSE}\right)$$

where I_{max} is the maximum possible intensity value of the image.

- For monochromatic gray scale image: $I_{max} = 255$
- Lower MSE (larger PSNR) means better image quality.
- "Source rate" means the average number of bits spent per pixel (bpp). For a given PSNR value, the lower the source rate is, the better the compression will be.

Progressive Source Compression



0.01bpp, PSNR=22.55dB

- Ex: SPIHT image compression algorithm [1]. 4% gives you only a brief description of the source.

[1] A. Said and W. A. Pearlman, "A New Fast and Efficient Image Codec Based on Set Partitioning in Hierarchical Trees," *IEEE Trans. on Circuits and Systems for Video Tech.*, vol. 6, pp.243-250, June 1996.

Progressive Source Compression

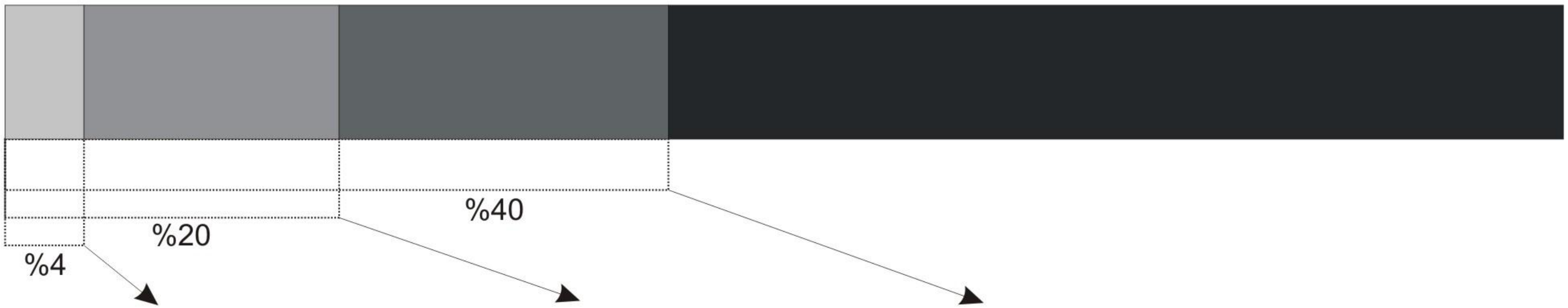
0.01bpp, PSNR=22.55dB

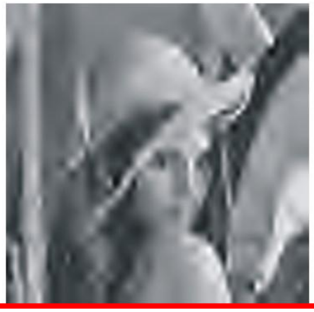
0.05bpp, PSNR=27.17dB

- 20% is good enough to say what the picture looks like.

Progressive Source Compression

SPIHT Encoded Bit Stream





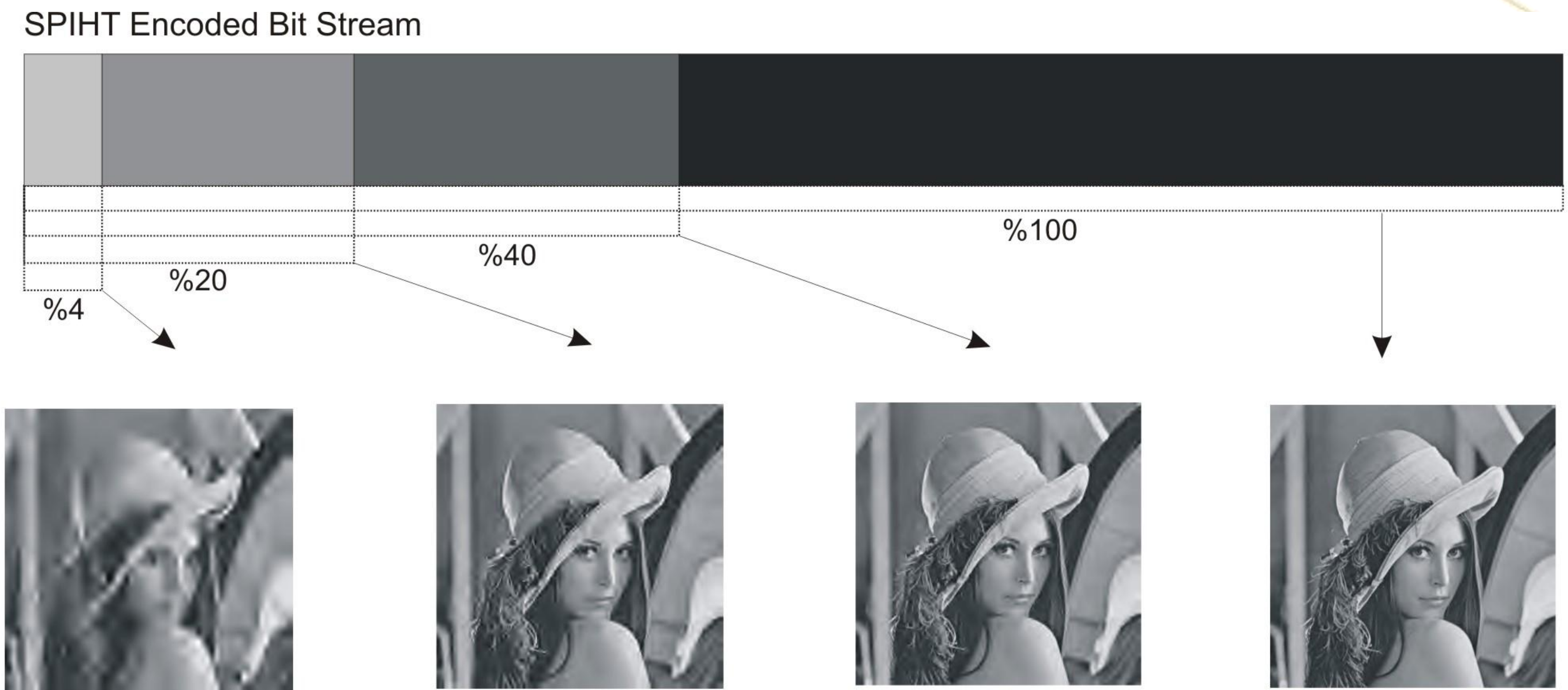
0.01bpp, PSNR=22.55dB

0.05bpp, PSNR=27.17dB

0.1bpp, PSNR=29.81dB

- At 40%, it begins to refine the image.

Progressive Source Compression



0.01bpp, PSNR=22.55dB | 0.05bpp, PSNR=27.17dB | 0.1bpp, PSNR=29.81dB | 0.25bpp, PSNR=33.68dB

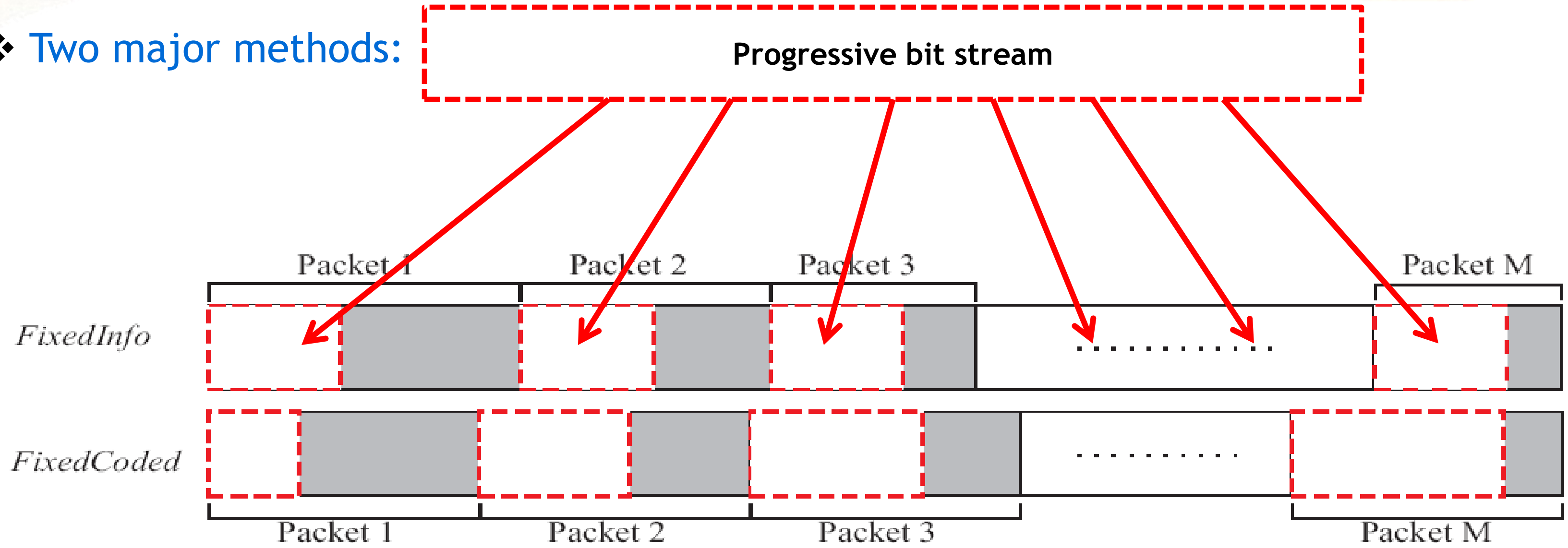
- At 100%, it gives more refinement but no major difference from 40%.

Progressive Source Compression

- We consider progressive type of encoders.
  - Embedded image encoders: EZW, SPIHT, JPEG2000 etc.
  - Image compression using singular value decomposition (SVD).
- Result: Very sensitive to bit errors.
- Protection and performance improvement is achieved by error correction coding.
- Way to go: Unequal error protection (UEP) is beneficial for progressively encoded sources. This can be provided by several known techniques.
- We consider a concatenated coded scheme.

Unequal Error Protection Schemes: **REVIEW**

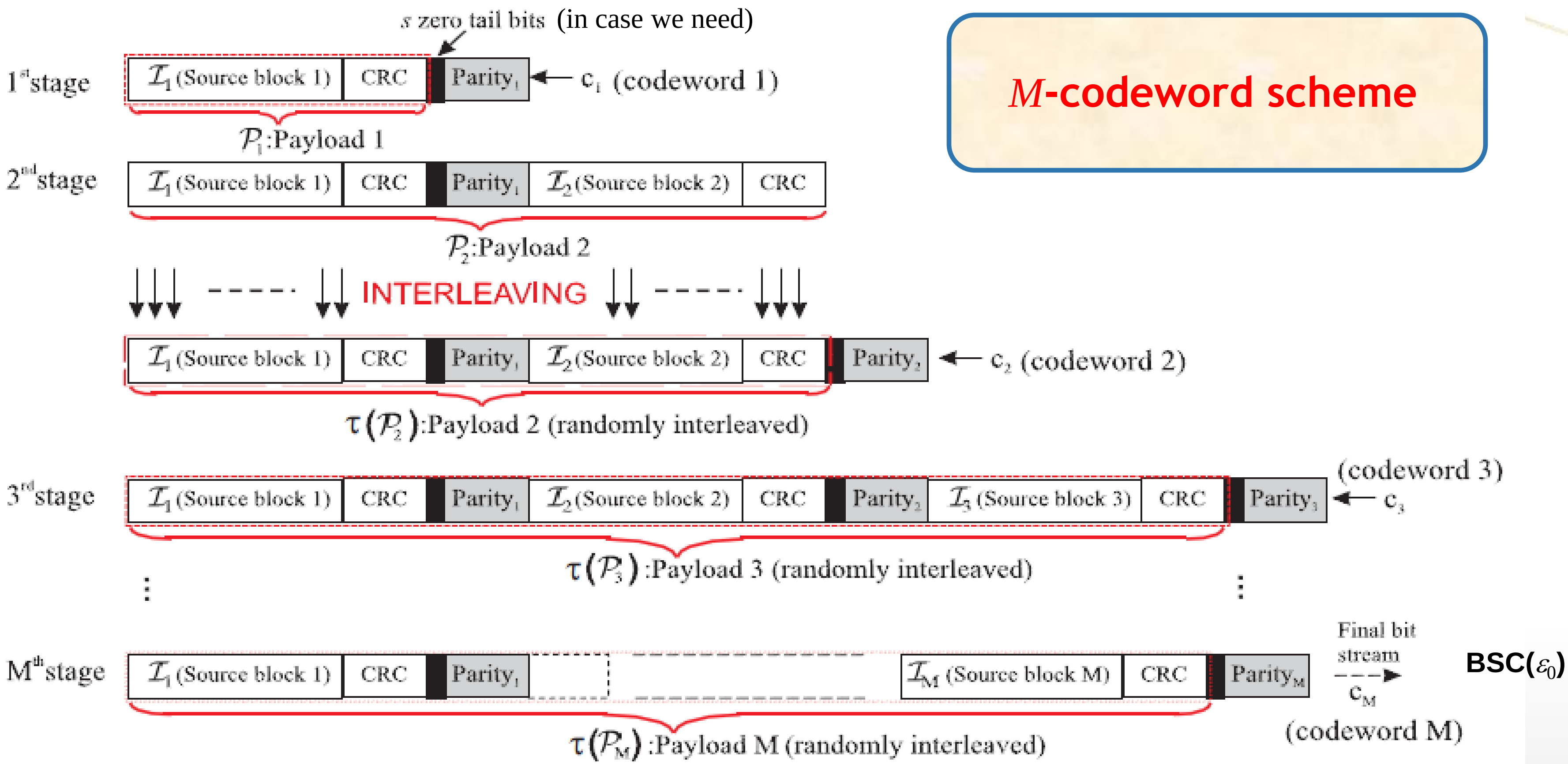
❖ Two major methods:



- *FixedInfo*, single channel code rate for all the packets.
- *FixedCoded*, single channel code rate for all the packets.
- *FixedInfo & FixedCoded*, different channel code rates for each packet.

- Error Correction Codes include:
  - Conventional Block Codes (BCH, Golay, etc),
  - Rate-Compatible Punctured Convolutional (RCPC) Codes,
  - Rate-Compatible (RC) Turbo codes, RC-LDPC codes
  - Reed Solomon (RS) codes.

Concatenated Block Coding for embedded bit stream transmissions



***M*-codeword scheme**

- Find the number of source blocks M, the rate of channel codes based on a bit budget constraint (Transmission rate) and a target error rate using minimum average distortion criterion.

Few results…

Use 512 X 512 *Lena* Image

RCPC codes with rates:

C = *{8/9, 4/5 , 2/3, 4/7, 1/2, 4/9, 2/5, 4/11, 1/3, 4/13, 2/7, 4/15, 1/4}*

bit budget

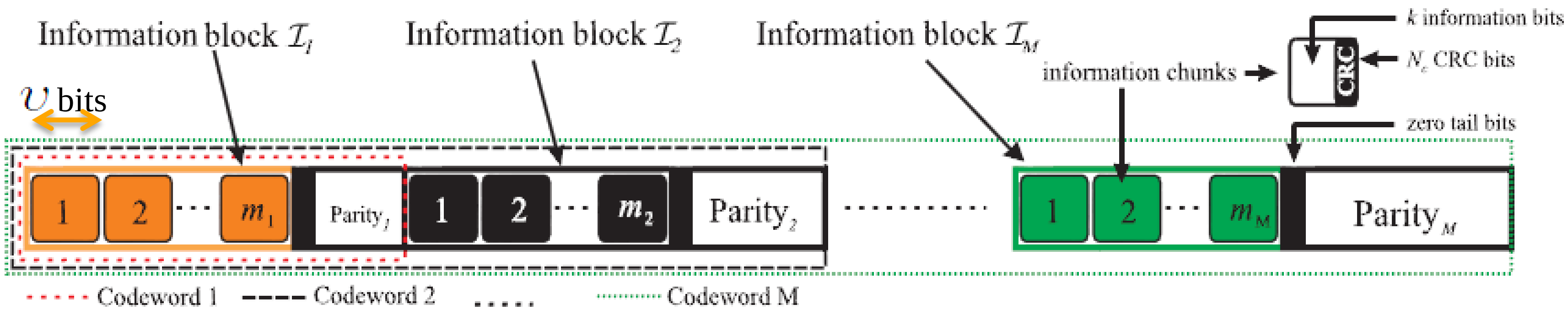
$\varepsilon_0 = 0.1$ and transmission rate ($\mathbf{r}_{tr}$) = *0.3bpp (0.3 X 512 X 512 = 79643 bits)*

M	r_1	r_2	r_3	r_4	r_5	PSNR (dB)
1	1/4	-	-	-	-	20.44
2	2/3	1/3	-	-	-	28.45
3	8/9	4/5	4/13	-	-	28.71
4	**8/9**	**8/9**	**4/5**	**1/3**	**-**	**28.79**
5	1	8/9	8/9	4/5	1/3	28.75

Observations

- In an optimal setting, this coding scheme results in four or five source blocks.
- Number of reconstruction levels is five or six.
- Result: User dissatisfaction due to large quality fluctuations.
- We consider a broadcast scenario.
  - One server, multiple receivers with varying channel conditions.
- Minimum average distortion.
  - Sufficient for point-to-point communication.
  - Minimum average does not imply minimum variance.
- Result: User dissatisfaction due to unfair service quality.

Extension System and Optimization



- M codewords. Each information block is chopped.
- Number of reconstruction levels: $\sum_{l=1}^{M} m_l + 1$
- This extensions increases the redundancy due to CRC.
  - Less space for source bits:

$$\sum_{l=1}^{M} \mathcal{I}_l - (m_l - 1)N_r \leq \sum_{l=1}^{M} \mathcal{I}_l$$

Extension System and Optimization

- Original Problem: A code allocation policy π allocates the channel code $c_\pi^{(i)} \in \mathcal{C}$ to be used in the i-th stage of the algorithm.
- Let $\overline{D}_\pi(n)$ denote the n-th moment of the distortion at the receiver using policy π .
- Let N_s be the number of source samples B is the bit budget.
- Minimum Average Distortion Problem:

$$\min_{\pi,\xi,\upsilon} \overline{D}_\pi(1) \text{ such that } r_{tr} = \frac{1}{N_s} \sum_{i=1}^{M} \frac{m_i \upsilon}{\prod_{j=i}^{M} r_\pi^{(j)}} \leq B$$

$$\xi = \{m_1, \ldots, m_M\}$$

Extension System and Optimization

- Constrained Minimization of Distortion Variance:

$$\min_{\pi,\xi,\upsilon} \sigma_\pi^2 \text{ such that } r_{tr} = \frac{1}{N_s}\sum_{i=1}^{M}\frac{m_i\,\upsilon}{\prod_{j=i}^{M} r_\pi^{(j)}} \le B, \overline{D}_\pi(1) \le \gamma_D$$

$$\sigma_\pi^2 = \overline{D}_\pi(2) - \overline{D}_\pi^2(1)$$

- **Assume:** σ_π^2 is a non-increasing function of $\overline{D}_\pi(1)$ using policy π
- Minimization of Second moment of Distortion: Set $\overline{D}_\pi(1) = \gamma_D$

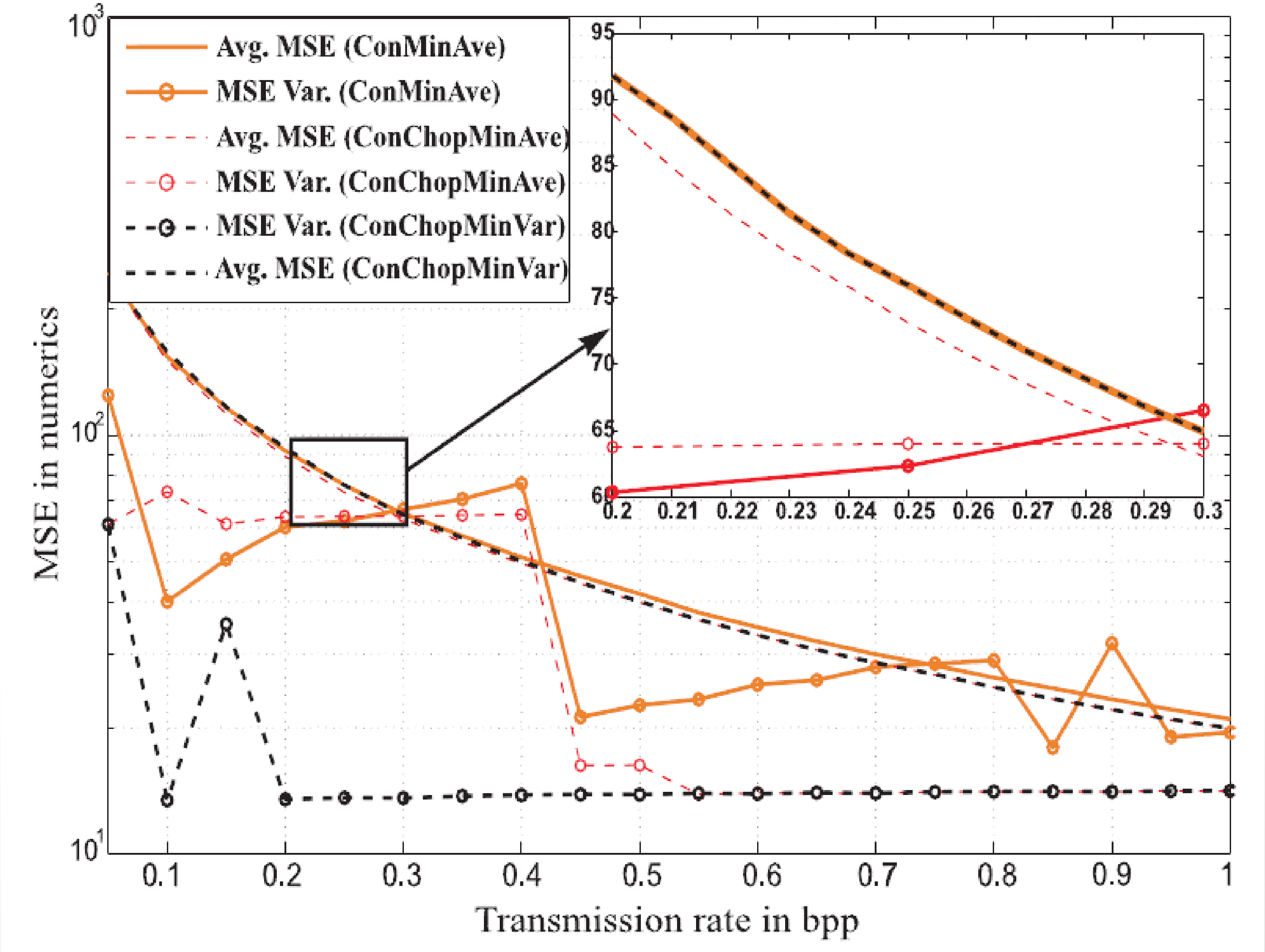
$$\min_{\pi} \overline{D}_\pi(2) \text{ subject to } r_{tr} = \frac{1}{N_s}\sum_{i=1}^{M}\frac{m_i\,\upsilon}{\prod_{j=i}^{M} r_\pi^{(j)}} \le B$$

Numerical Results

- We compare the following systems:
  - ***ConMinAve*:** Concatenated block coding with minimum average distortion criterion. Let d^* be the minimum distortion. (**Original System** **[1]**)
  - ***ConChopMinAve*:** Extension scheme with minimum average distortion criterion.
  - ***ConChopMinAve*:** Extension scheme with minimum distortion variance criterion subject to a minimum average distortion constraint $\gamma_D \leq d^*$
- We use a 512 X 512 monochromatic images Lena and Goldhill using SPIHT and JPEG2000 compression algorithms.
- Let us set υ = 850, M = 2, and use RCPC codes [1].
- A **BSC** with crossover probability $\varepsilon_0 = 0.05$.
- Our distortion metric is MSE and we present the mean MSE and MSE variance for all three systems.

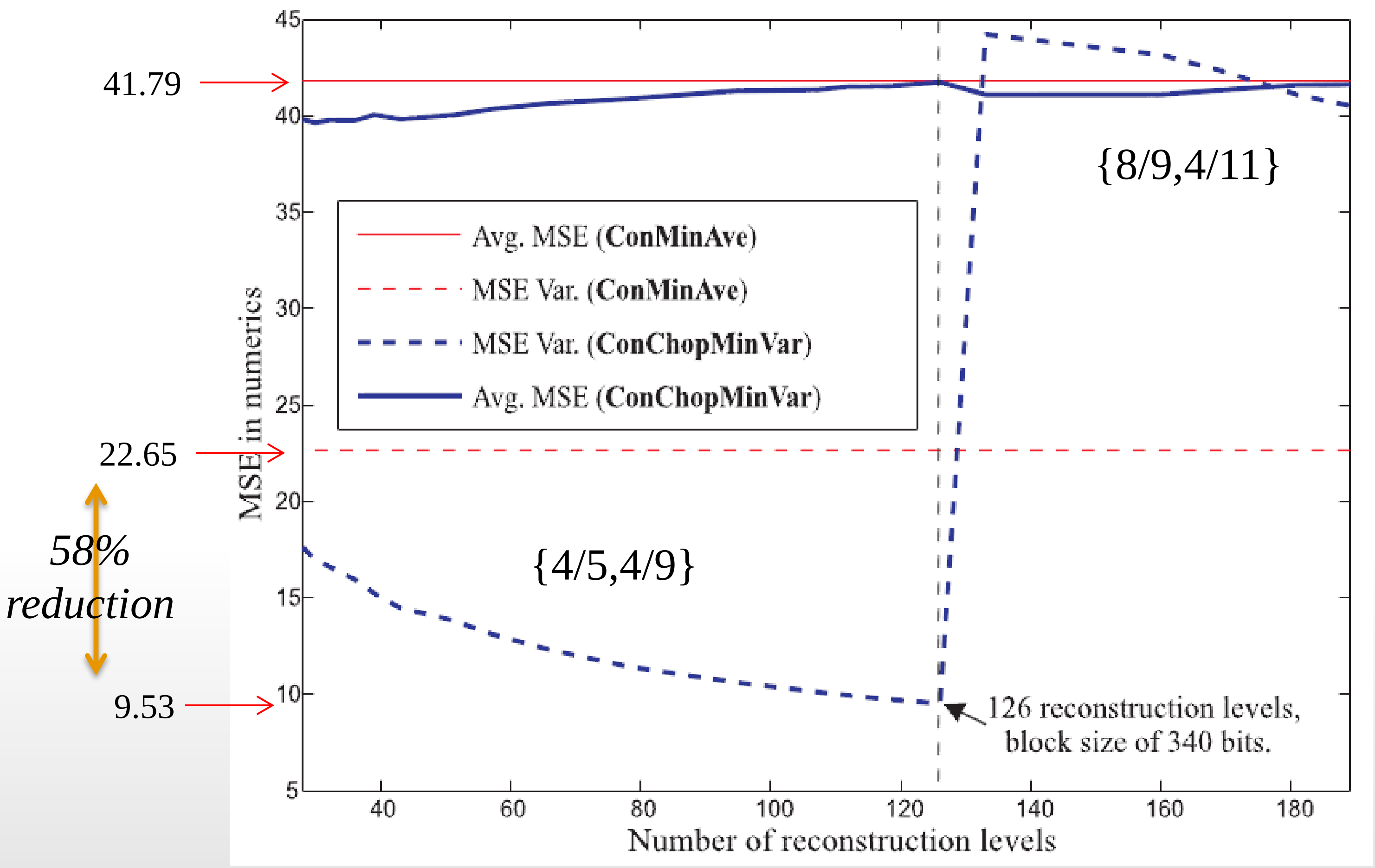
[1] S. S. Arslan, P. C. Cosman and L. B. Milstein, "Concatenated Block Codes for Unequal Error Protection of Embedded Bit Streams,"Submitted to IEEE Trans. on Image Processing.

Numerical Results



Numerical Results

- Let us vary υ , to increase/decrease the number of reconstruction levels.
- Set M = 2.



Numerical Results

Image	r_{tr}(bpp)	Results (Std. dev.)	Channel raw BER (ϵ_0)			Image	Channel raw BER (ϵ_0)	
			0.1	0.05	0.01		0.05	0.01
Lena (SPIHT)	0.25	ConMinAve	89.9	62.33	52.68	Goldhill (JPEG2000)	73.95	59.95
		ConChopMinVar	19.62	12.79	8.58		24.25	17.11
		Percentage decrease	78.17%	79.48%	83.71%		67.20%	71.46%
	0.5	ConMinAve	26.75	22.65	16.34		99.92	18.73
		ConChopMinVar	16.33	9.53	7.66		24.55	16.87
		Percentage decrease	38.95%	57.92%	53.12%		75.43%	9.93%
	0.8	ConMinAve	34.77	28.99	15.11		24.55	16.87
		ConChopMinVar	16.03	4.92	2.65		9.18	17.01
		Percentage decrease	53.9%	83.03%	82.46%		73.93%	30.29%

- Dramatic improvements can be obtained while maintaining the good mean distortion characteristics.
- Similar results can be observed using RC-LDPC codes.

References

[1] A. Said and W. A. Pearlman, "A New Fast and Efficient Image Codec Based on Set Partitioning in Hierarchical Trees," *IEEE Trans. on Circuits and Systems for Video Tech.*, vol. 6, pp.243-250, June 1996.

[2] S. S. Arslan, P. C. Cosman and L. B. Milstein, "Concatenated Block Codes for Unequal Error Protection of Embedded Bit Streams,"Submitted to IEEE Trans. on Image Processing.

[3] P. G. Sherwood and K. Zeger "Progressive Image Coding for Noisy Channels," *IEEE Signal Process. Lett.*, vol. 4, No. 7, pp.189-191, July 1999.

[4] A. Nosratinia, J. Lu, and B. Aazhang, "Source-channel rate allocation for progressive transmission of image," *IEEE Trans. Communications*, vol. 51, no. 2, Feb. 2003.

[5] L. Li and M. Salehi, "Hierarchical Image Coding Matched to Unequal Error Protection Rate Compatible Punctured Convolutional Codes," *Proceedings of the IEEE International Conference on Robotics, Intelligent systems and Signal Processing*, vol.1, pp.238 - 243. Oct. 2003.

[6] B. A. Banister, B. Belzer, and T. R. Fisher, "Robust image transmission using JPEG2000 and turbo codes," *IEEE Signal Process. Lett.*, vol. 9, no. 4, pp.117-119, Apr. 2002

[7] T. Thomos, N. V. Boulgouris and M. G. Strintzis, "Wireless Image Transmission Using Turbo Codes and Optimal Unequal Error Protection," *IEEE Trans. on Image Processing*, vol. 14, No. 11, pp.1890-1901, Nov. 2005.

[8] X. Pan, A. H. Banihashemi and A. Cuhadar, "Combined Source and Channel Coding With JPEG2000 and Rate-Compatible Low-Density Parity-Check Codes," *IEEE Trans. on Signal Processing*, vol. 54, no 3, pp.1160 - 1164, March 2006.