Weber's law-based side-informed data hiding

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Outline

- Introduction
- Constraints definition
- Embedding strategy
- Variance analysis
- Probability of decoding error
- Experimental results
- Conclusions

Introduction

- Data hiding: a lot of attention has been paid to
  - Capacity
  - Probability of decoding error
  - Robustness
  - Detectability (steganography)
  - Security
- But, perceptual impact is usually undervalued
- Of all the characteristics of the Human Visual System, in this work we will focus on Weber’s law

Introduction

- Basic idea:
  - If one is carrying 1 Kg parcel, he will feel if 200 gr are added
  - If one is carrying 50 Kg parcel, he will probably not feel if 200 gr are added

Original signal

Modified signal

Perceptual impact is not equivalent!!

Modified signal with equivalent perceptual impact

Introduction

- Basic idea:
  - If one is carrying 1 Kg parcel, he will feel if 200 gr are added
  - If one is carrying 50 Kg parcel, he will probably not feel if 200 gr are added

- Weber’s law: the modification a signal must undergo in order to produce the smallest noticeable difference is porportional to the magnitude of the signal itself

Introduction

- Weber's law is implicitly used by Multip.-SS methods
- They are outperformed by side-informed data hiding schemes
- Could the perceptual advantages of Multip.-SS be exploited by side-informed techniques?
- Weber's law is used for deriving a generalized version of a previous logarithmic embedding scheme
- Several choices of embedding and decoding regions are proposed

Constraints definition

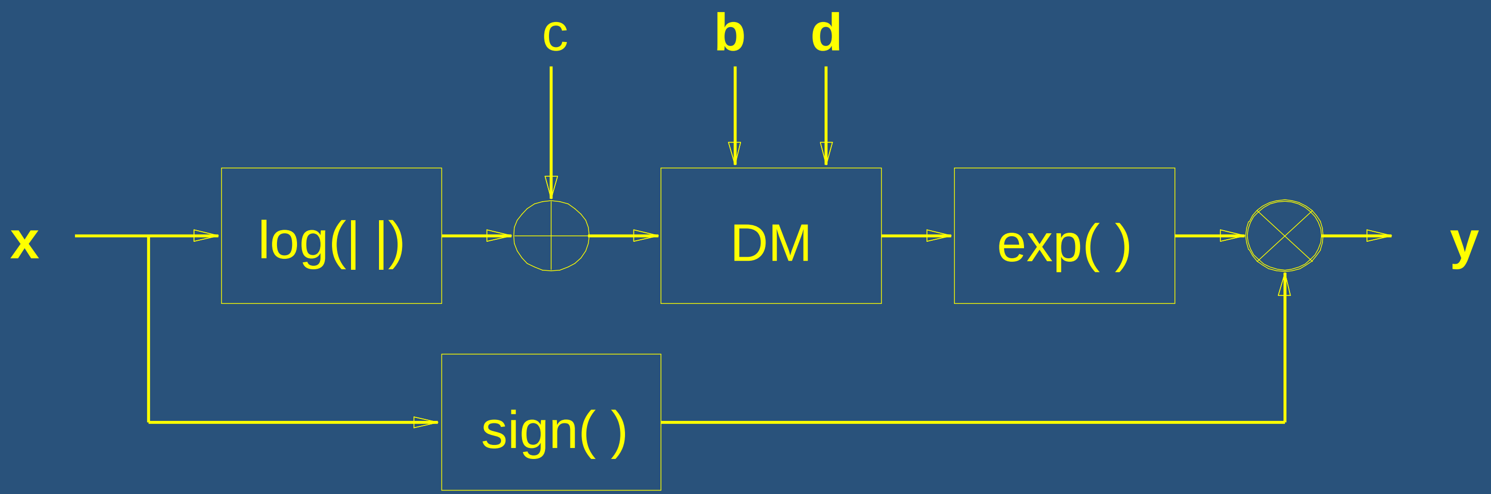
- From Multip.-SS: $|w_i| \leq \eta|x_i| \cdot |s_i|$
  - We will establish the constraint $\eta_1 x_i < w_i \leq \eta_2 x_i$

where $\eta_1 < 0$ and $\eta_2 > 0$

- From side-informed embedding: quantize the host signal depending on the hidden bit
- Robustness:
  - Centroids density is required to be minimum
  - The total codebook can be determined by knowing any of its codewords
- Embedding strategy:

$$\log(|y_i|) = Q_\Delta\left(\log(|x_i|) - \frac{b_i\Delta}{2} - d_i + c - \frac{\Delta}{2}\right) + \frac{b_i\Delta}{2} + d_i$$

Embedding strategy

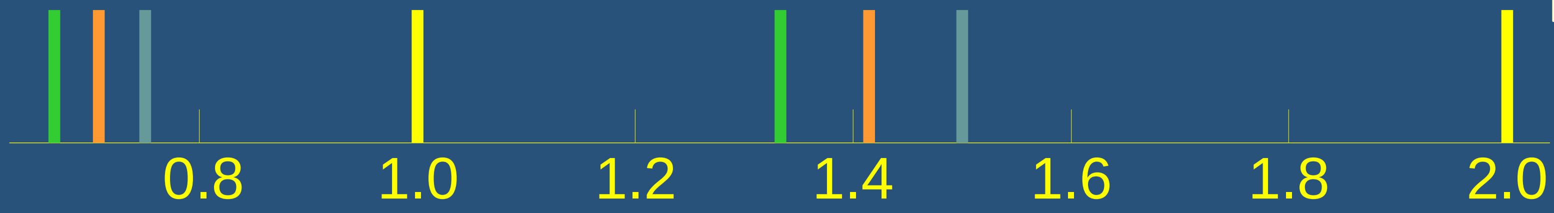


- $0 \le c \le \Delta$, defines quantization region boundaries
- d_i: dither
- $\gamma = \exp(\Delta)$
- $c = \log(1 + \eta_2)$
- Generalized Logarithmic DM

Embedding strategy

- $\eta_2 = \frac{\gamma - 1}{\gamma + 1}$: quantization boundary at the middle of the centroids. Multiplicative DM
- $\eta_2 = \sqrt{\gamma} - 1$: centroid at the geometric mean value of the quantization interval. Logarithmic DM
- $\eta_2 = \frac{\gamma - 1}{2}$: centroid at the arithmetic mean value of the quantization interval
- $\gamma \rightarrow 1$, all of them are asymptotically equivalent

Embedding strategy



- Centroids
- $\eta_2 = \frac{\gamma - 1}{\gamma + 1}$
- $\eta_2 = \sqrt{\gamma} - 1$
- $\eta_2 = \frac{\gamma - 1}{2}$
- Decoding: minimize quantization error considering $0 \leq c' \leq \Delta/2$
- Choice of c at the embedder and c' at the decoder could be different

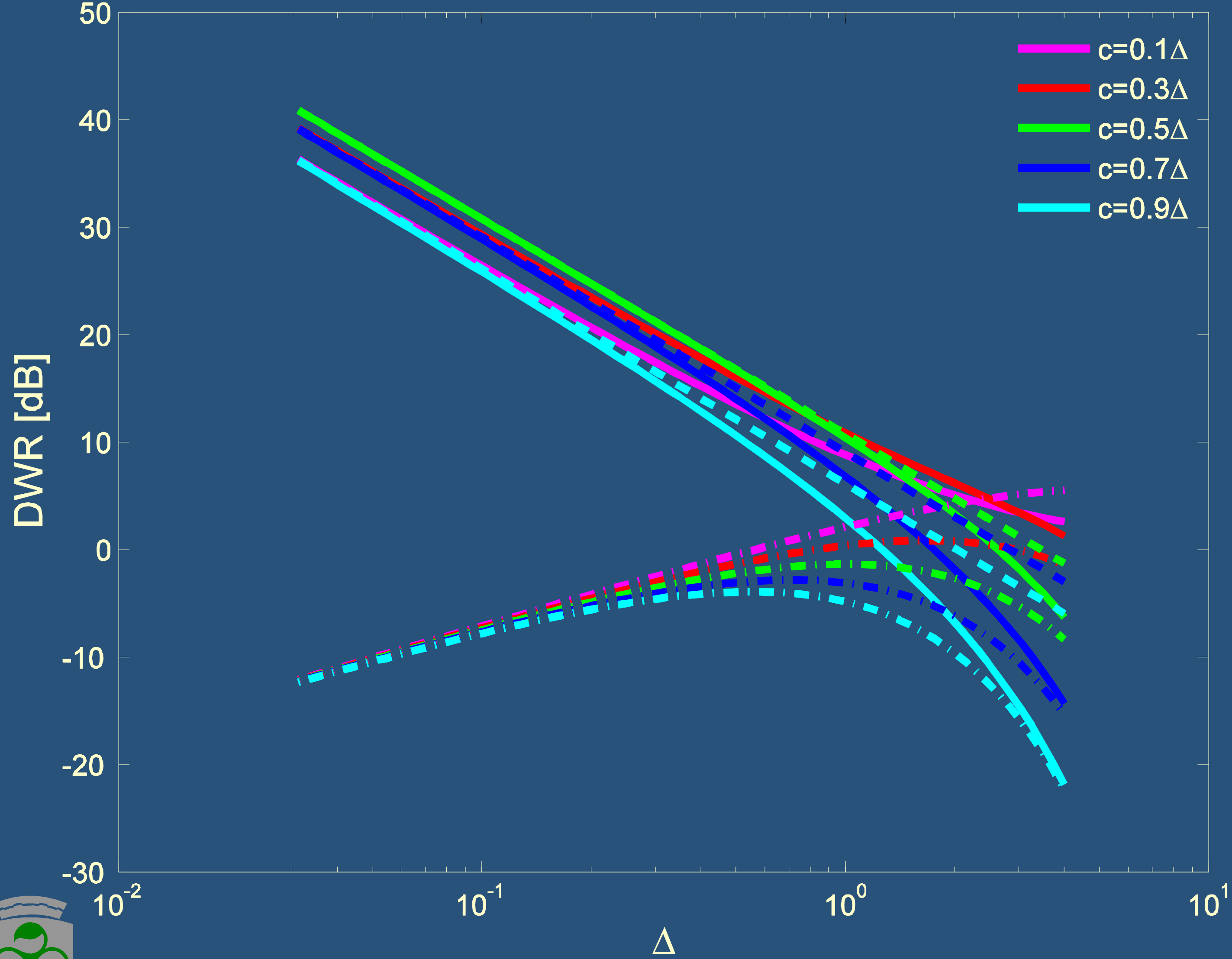
Variance analysis

- Exact formula of embedding variance

$$\frac{1}{\Delta}\int_{-\Delta/2}^{\Delta/2}\left(\sum_{m=-\infty}^{\infty}\int_{e^{m\Delta+\tau-c}}^{e^{m\Delta+\Delta+\tau-c}}(|x|-e^{m\Delta+\tau})^2 f_{|X|}(|x|)dx\right)d\tau$$

- For $\Delta << 1$, $\sigma_W^2 \approx \sigma_X^2 \frac{1}{3\Delta}\left[c^3+(\Delta-c)^3\right]$
  - Minimum at $c=\Delta/2$
  - Maxima at $c=0$ and $c=\Delta$
- For $\Delta >> 1$, $\sigma_W^2 \approx \frac{\sigma_X^2 \; e^{2c}}{2\Delta}$
  - Non-realistic case, but interesting to check the deviation from Δ << 1 case

Variance analysis



- Continuous lines: empirical results
- Dashed lines: approx. for Δ << 1
- Approxs. for $c = 0.1\Delta$ and $c = 0.9\Delta$, and $c = 0.3\Delta$ and $c = 0.7\Delta$

overlap

- Dash-dot lines: approx. for Δ >> 1

Probability of decoding error

- Minimum distance decoder:

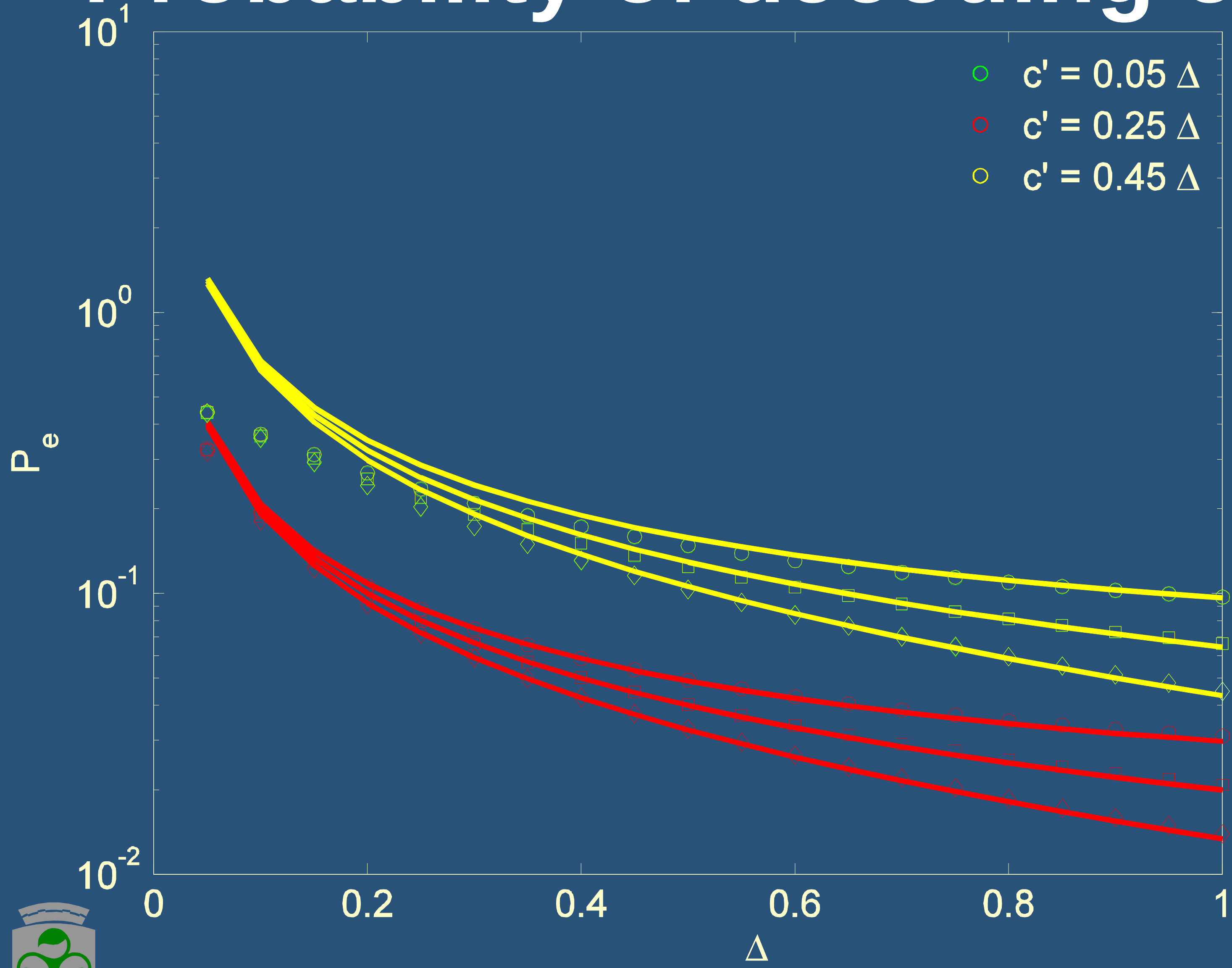
$$P_e = \Pr\left\{\left|\text{mod}\left(\log(|Z_i|) - D_i + c' - \frac{\Delta}{4}, \Delta\right)\right| \geq \Delta/4\right\}$$

- $\Delta << 1$

$$P_e \approx \frac{2\sigma_N e^{\Delta/2-c}}{\Delta\sigma_X \sin\left(\frac{2\pi c'}{\Delta}\right)}$$

- Minimized at $c \to \Delta$ and $c' = \Delta/4$
- For $\Delta << 1$, there is a trade-off between probability of decoding error and embedding power with c
- In any case, if $\Delta << 1$ the optimal c will be in $[\Delta/2, \Delta]$

Probability of decoding error



- Symbols empir.
- Lines theoret.
- Circles

  $c = 0.1\Delta$
- Squares

  $c = 0.5\Delta$
- Diamonds

  $c = 0.9\Delta$
- Results for

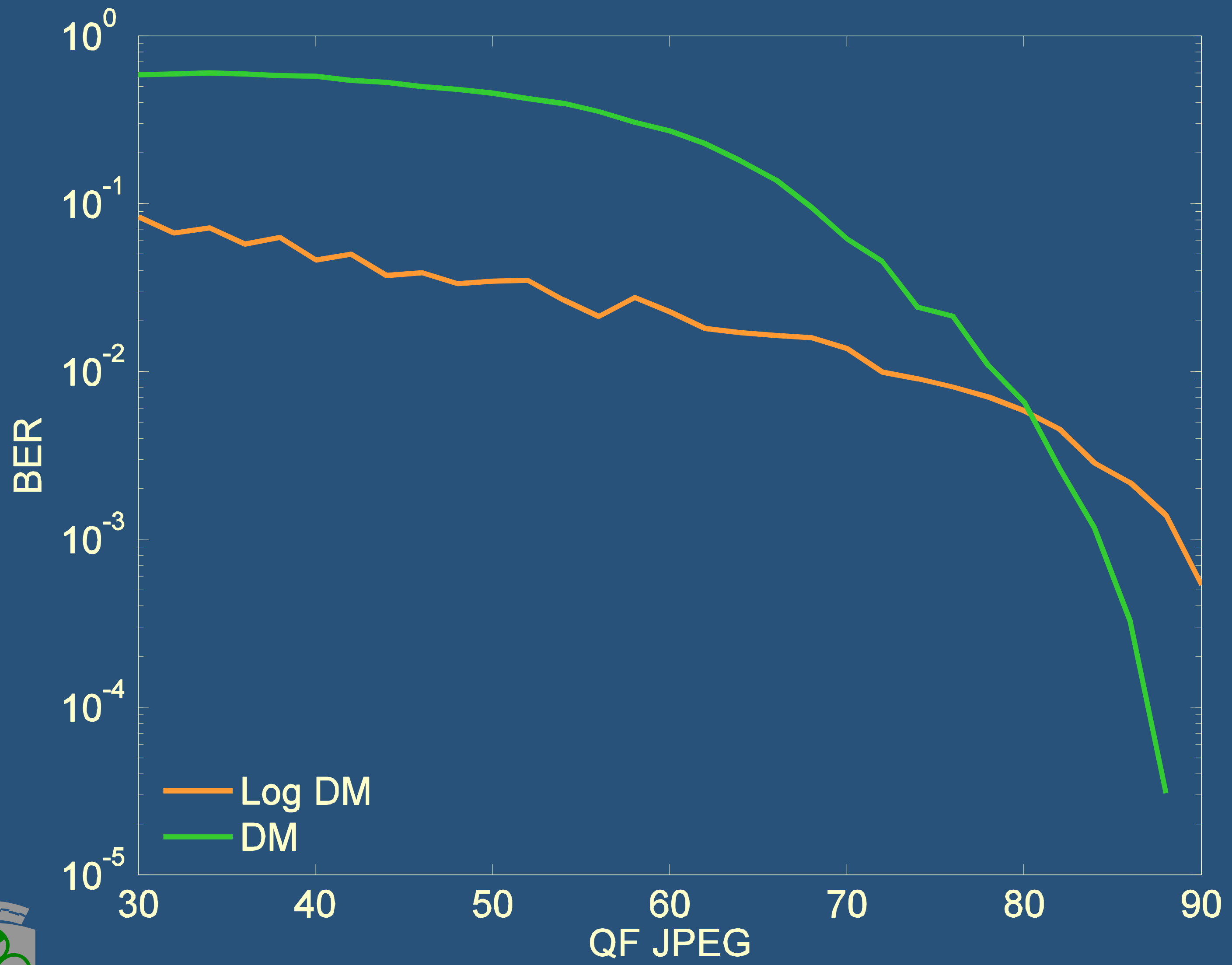
  $c' = 0.05\,\Delta$

and

$c' = 0.45\,\Delta$

are overlapped

Experimental results

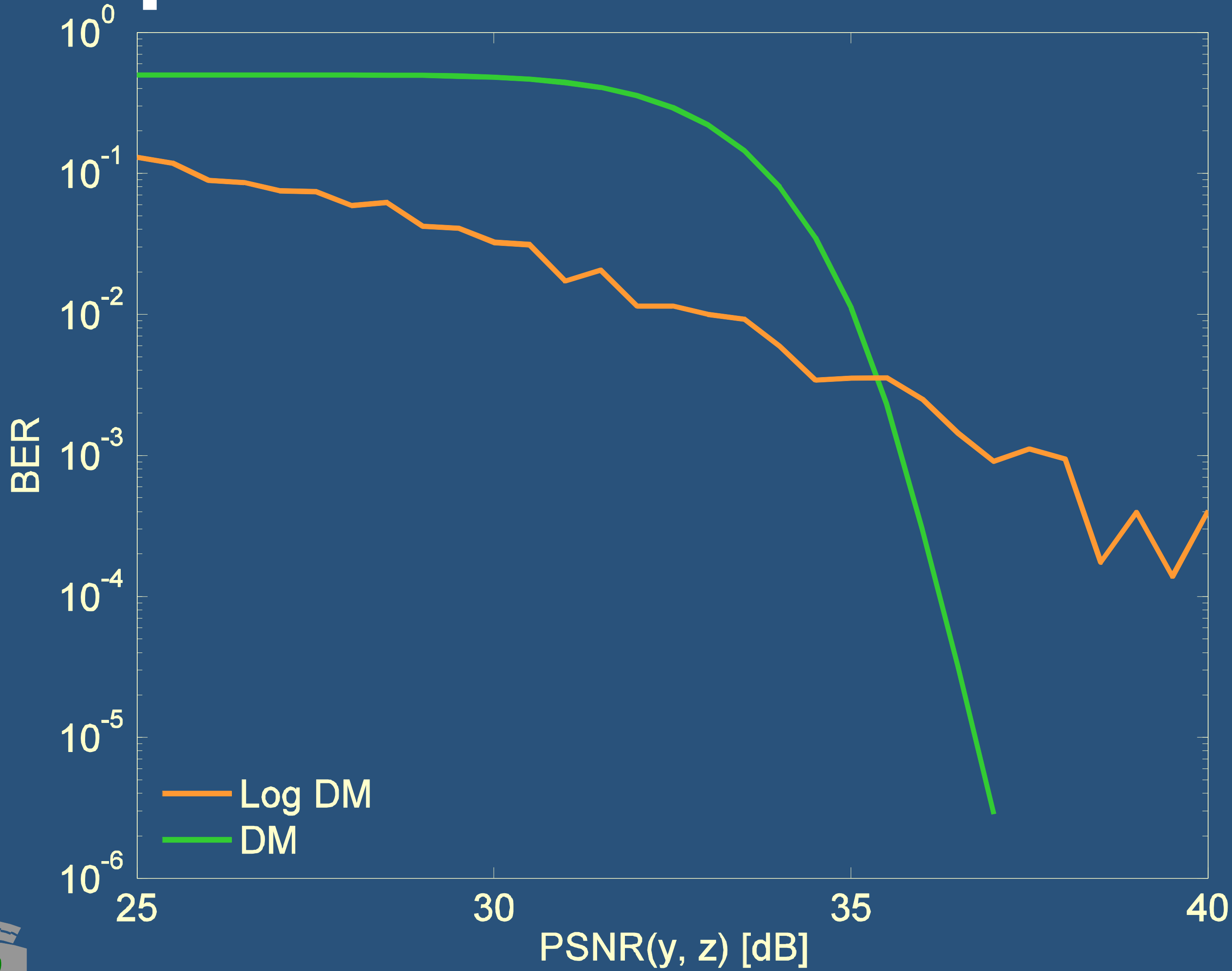


- BER vs. JPEG QF
- Repetition rate = 1/100
- 8x8 DCT domain
- For Log. DM only the 5 coefficients with largest magnitude are considered

$\Delta_{DM} = 30$

$\Delta_{Log.\ DM} = 30$

Experimental results



- BER vs. PSNR AWGN
- Repetition rate = 1/100
- 8x8 DCT domain
- For Log. DM only the 5 coefficients with largest magnitude are considered

$\Delta_{DM} = 30$

$\Delta_{Log.\ DM} = 30$

Conclusions

- Weber's law is followed to derive perceptually shaped side-informed watermarking systems
- A generalized version of logaritmic DM is derived
- Embedding variance and probability of decoding error performance analysis is performed
- The proposed schemes outperform DM when severe attacks are considered