Training Method (3)

- Our model contains complicated non-differentiable layers
  - Long-delay multipath communication channel
  - Practical transmitter and receiver filters
  - Time-domain adaptive equalizer (TD-AE) to mitigate ISI

  ➨ It is difficult to train the encoder/decoder from sctatch

- Two-step training procedure to overcome this difficulty
  - **Pre-Training**: Employs a simple AWGN channel model
    - ➨ Suitable initial values for the parameters are obtained
  - **Main-Training**: Employs the targeted system model

Numerical Simulation

Simulation Parameters

- We employed a two-path channel model

For comparison, we employed

- Image compression:
  JPEG, JPEG2000
- Modulation:
  - QPSK, 16QAM
- Forward error correction:
  - Turbo code (1/2, 3/4)

(Channel parameters are taken from [4])

Item	Value
# of antennas	2
Carrier freq.	300 kHz
System bandwidth	200 kHz
# of training symbols	4000
Roll-off rate of RRC filters	0.2
# of FIR taps in TD-AE	21
SNR	18–26 dB
Relative moving speed	1 m/s
Relative delay of delay wave	520 samples
Relative power ratio $L_i^{(k,l)}$	0.4
Speed of sound	1500 m/s
Incident angle $\alpha_i^{(k,l)}$	Random
Initial phase $\phi_i^{(k,l)}$	Random

[4] H. Fukumoto et al., in *Proc. Global Oceans 2020*, 2020.

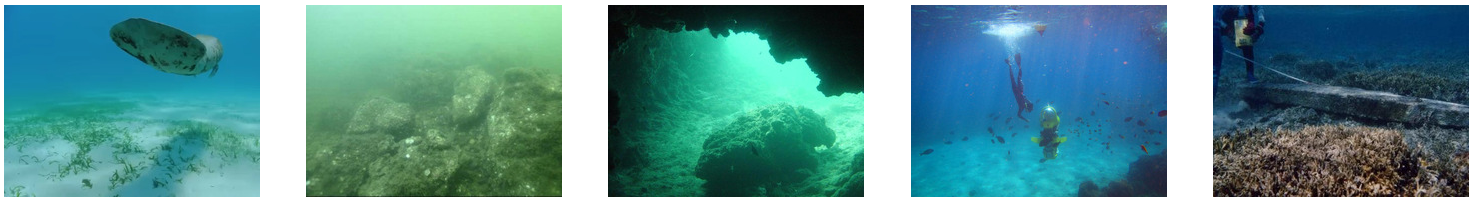
Datasets

- Training dataset : Downsampled Imagenet[5]
  - Consists of many 32×32 color images
    (1,281,167 for training and 50,000 for validation)

[5] P. Chrabaszcz et al., arXiv preprint, arXiv:1707.08819, 2017.

Datasets

- Training dataset : Downsampled Imagenet[5]
  - Consists of many 32×32 color images
    (1,281,167 for training and 50,000 for validation)
- Test dataset : Underwater image dataset[6] (890 images)



[5] P. Chrabaszcz et al., arXiv preprint, arXiv:1707.08819, 2017.
[6] C. Li et al., in *IEEE Trans. Image Process.*, vol. 29, pp. 4376–4389, 2020.

Datasets

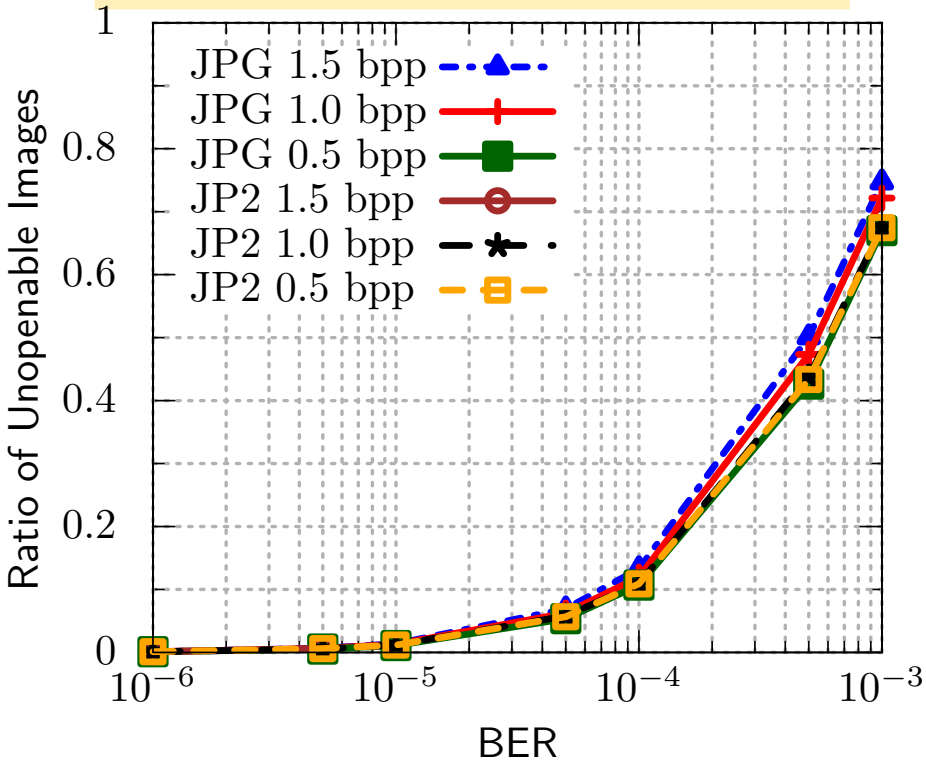
- Training dataset: Downsampled Imagenet[5]
  - Consists of many 32×32 color images
    (1,281,167 for training and 50,000 for validation)
- Test dataset: Underwater image dataset[6] (890 images)
  - Preprocessed to obtain equal-size images
    - Extract images with $(\text{width}/\text{height}) \geq 4/3$ (825 images)
    - Resize and crop to obtain images with 256×192 pixels

[5] P. Chrabaszcz et al., arXiv preprint, arXiv:1707.08819, 2017.
[6] C. Li et al., in *IEEE Trans. Image Process.*, vol. 29, pp. 4376–4389, 2020.

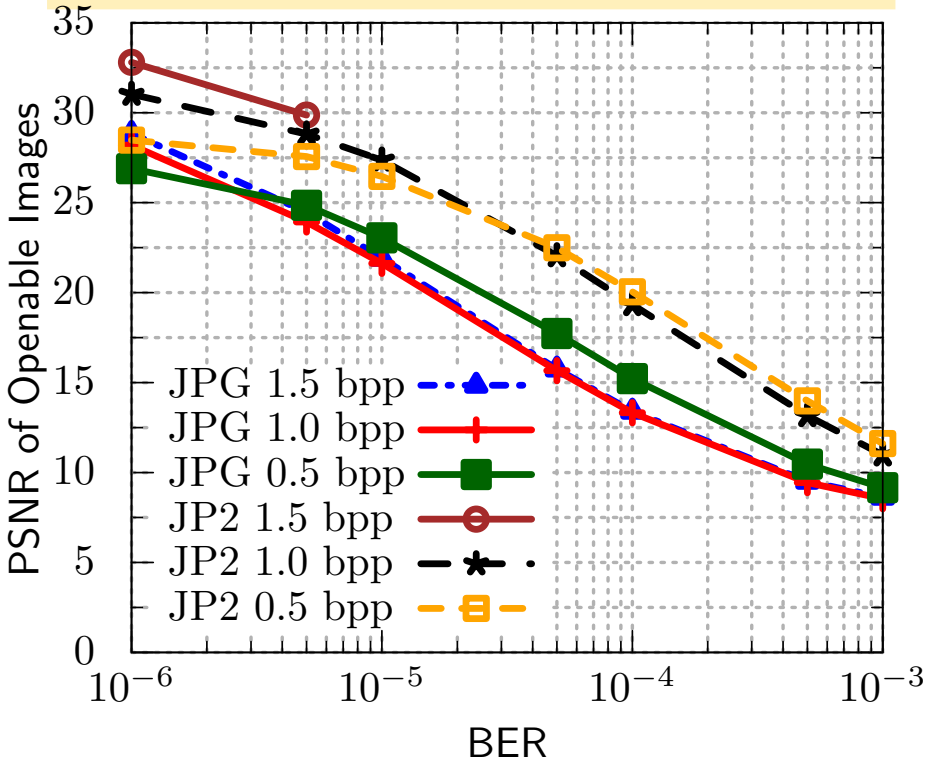
Selection of Baseline Scheme (1)

- Effect of the bit error rate (BER) on the received image quality

Ratio of unopenable images



Received image quality (PSNR)



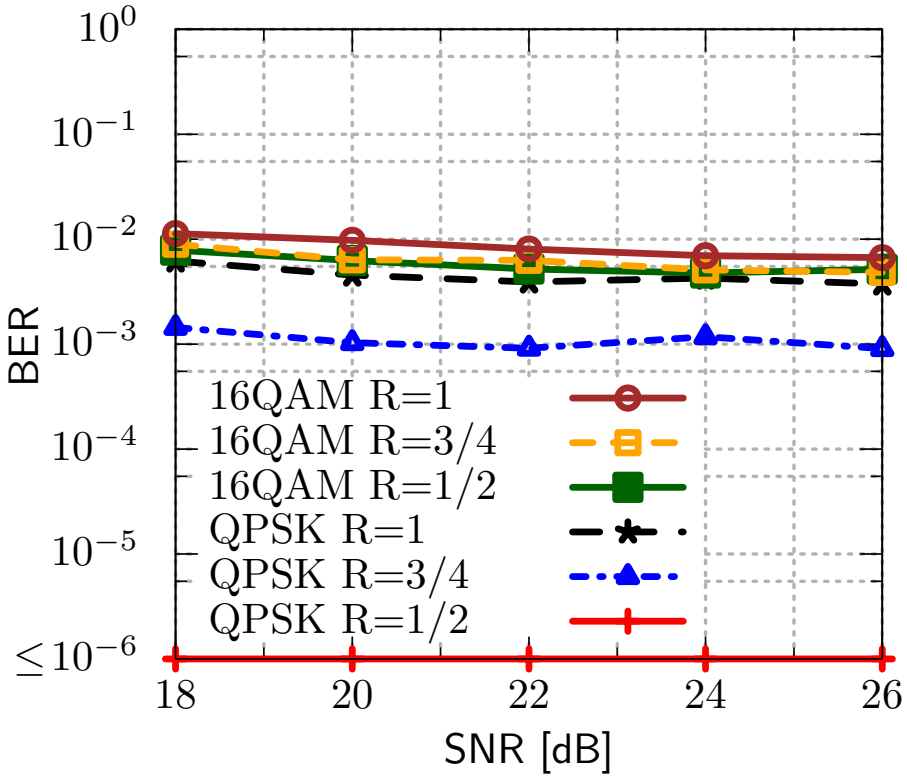
bpp: bit per pixel (compression metric)

$$\mathrm{PSNR} = 10\log_{10}\frac{255^2}{\mathrm{MSE}}$$

BER $\leq 10^{-6}$ is required to stably receive JPEG/JPEG2000 images

Selection of Baseline Scheme

- BER curves for QPSK and 16QAM (R: Code rate)



- QPSK ($R = 1/2$):
  - The only scheme with $\mathrm{BER} \leq 10^{-6}$ (among those in the figure)

➡ The baseline scheme we employ for comparison

In what follows, we suppose $\mathrm{BER} = 0$ for $\mathrm{SNR} \geq 18\mathrm{dB}$

Performance Evaluation (1)

- Trained the encoder/decoder with 0.5 symbols per pixel (spp)
  - Each 256×192 image is converted to $24,576$ symbols
- The symbol-set size $|S|$ was set to 256
- 70,000 training steps (including 40,000 pre-training steps)

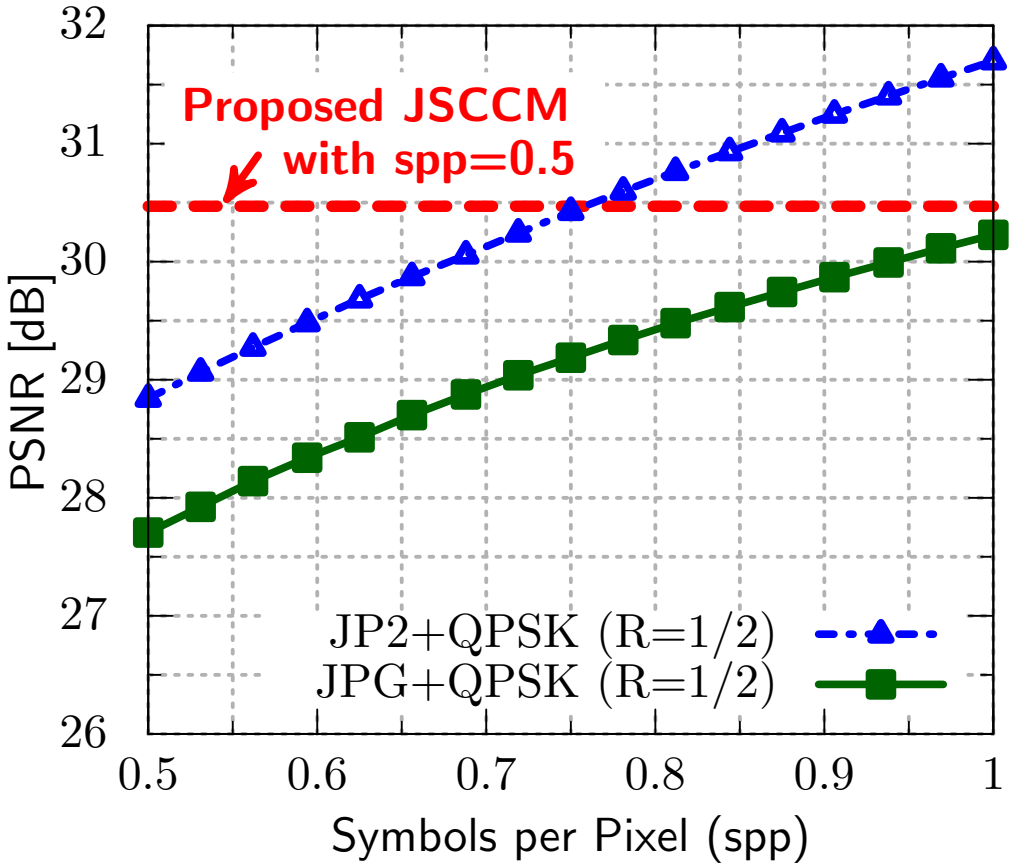
Comparison of the proposed JSCCM with the baseline scheme

- Average PSNR of received images for SNR = 18 dB

Proposed JSCCM	QPSK + JPEG2000	QPSK + JPEG
30.470	28.842	27.706

Performance Evaluation (2)

Comparison of the proposed JSCCM with the baseline scheme



(Figure) Effect of the # of transmitted symbols on the received image quality

- To achieve the same quality as the proposed JSCCM
  - For JPEG2000, we need ~ 50% additional symbols
  - For JPEG, we need ~ 100% additional symbols

➡ **Large improvement in the transmission rate by the proposed JSCCM**

Summary

- Proposed a deep JSCCM scheme for underwater acoustic image transmission, considering
  - Long-delay multipath communication channel
  - Practical transmitter and receiver filters
  - Time-domain adaptive equalizer (TD-AE) to mitigate ISI
- Showed its effectiveness with simulation:
  - **~ 50% speed up** compared with JPEG2000+QPSK
  - **~ 100% speed up** compared with JPEG+QPSK
- Next step: Performance evaluation with real implementation

Example of Received Images

Original

Proposed JSCCM

JPEG2000 + QPSK

JPEG + QPSK

Trained Symbolset