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Underwater video transceiver designs based on channel state information and video content

Key words: Underwater video transmission; Transceiver design; Imperfect channel state information

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Motivation

- Underwater video transmissions have shown a great need in many applications recently. However, the underwater acoustic environment poses great challenges to the designs of video transmissions.
- The current designs often treat video coding and transmission schemes as individual modules. Few transmission schemes are designed based on video contents. And little information was exchanged to cope with the complicated channel conditions. Therefore, we are trying to design an adaptive video transmission system over underwater acoustic channels.

Main idea

1. Transceiver design

- Compress video data using 3D-DCT and segment the resultant coefficients into multiple chunks.
- Distribute different chunks to different subcarriers, and optimally schedule the power allocation based on their importance and the channel conditions.

2. Extend the design to the imperfect CSI case

System Model

1. Channel model

$$H_{u,v} = \frac{1}{N}\sum_{n=0}^{N-1}\sum_{\ell=0}^{L-1} h(n;\ell)e^{j\frac{2\pi}{N}[v(n-\ell)-un]}.$$

$$y_u = H_{u,u}x_u + \sum_{\substack{v=0\\ v\neq u}}^{N-1} H_{u,v}x_v + w_u,$$

Matrix-vector form: $\boldsymbol{y} = \boldsymbol{H}\boldsymbol{x} + \boldsymbol{w}.$

2. Precoder $\boldsymbol{x} = \boldsymbol{F}\boldsymbol{d}$

$$\boldsymbol{F} = \boldsymbol{V}\boldsymbol{\Phi}\boldsymbol{P},$$

where $\boldsymbol{V}$ is a unitary precoder, $\boldsymbol{\Phi}$ is a diagonal matrix for power allocation, and $\boldsymbol{P}$ is a permutation matrix for subcarrier location matching. The entry in the i-th row and ℓ-th column of $\boldsymbol{P}$ is denoted by $p_{i\ell}$.

3. Power constraint $tr(\boldsymbol{F}\boldsymbol{R}_D\boldsymbol{F}^H) = tr(\boldsymbol{\Phi}\boldsymbol{P}\boldsymbol{R}_D\boldsymbol{P}^H\boldsymbol{\Phi}^H) \leq P_0.$

4. Equalizer (MMSE) $\boldsymbol{G}_{opt} = \boldsymbol{R}_d\boldsymbol{P}^H\boldsymbol{\Phi}^H\left(\boldsymbol{\Phi}\boldsymbol{P}\boldsymbol{R}_d\boldsymbol{P}^H\boldsymbol{\Phi}^H + \boldsymbol{Z}^{-1}\right)^{-1} bmZ^{-1}\boldsymbol{V}^H\boldsymbol{H}^H\boldsymbol{R}_w^{-1},$

where $\boldsymbol{Z} = \boldsymbol{V}^H\boldsymbol{U}\boldsymbol{\Lambda}\boldsymbol{U}^H\boldsymbol{V}$ and $\boldsymbol{H}^H\boldsymbol{R}_w^{-1}\boldsymbol{H} = \boldsymbol{U}\boldsymbol{\Lambda}\boldsymbol{U}^H$

5. Error vector $e = \hat{d} - d = (GHV\Phi P - I)d + Gw.$

Problem Formulation

1. Perfect CSI

$$\xi(\boldsymbol{P}, \boldsymbol{\Phi}, \boldsymbol{V}, \boldsymbol{G}) = tr\{\mathbb{E}(\boldsymbol{e}\boldsymbol{e}^H)\} = tr\big((\boldsymbol{G}\boldsymbol{H}\boldsymbol{V}\boldsymbol{\Phi}\boldsymbol{P}-\boldsymbol{I})\boldsymbol{R}_d(\boldsymbol{G}\boldsymbol{H}\boldsymbol{V}\boldsymbol{\Phi}\boldsymbol{P}-\boldsymbol{I})^H\big) + tr(\boldsymbol{G}\boldsymbol{R}_w\boldsymbol{G}^H).$$

Problem.

$$\min_{\boldsymbol{V},\boldsymbol{\Phi},\boldsymbol{P},\boldsymbol{G}} \quad \xi(\boldsymbol{P}, \boldsymbol{\Phi}, \boldsymbol{V}, \boldsymbol{G}),$$
$$subject\ to \quad tr(\boldsymbol{\Phi}\boldsymbol{P}\boldsymbol{R}_d\boldsymbol{P}^H\boldsymbol{\Phi}^H) \le P_0.$$

2. Imperfect CSI

$$\mathbb{E}_{\boldsymbol{\Xi}}\big[\xi(\hat{\boldsymbol{P}}, \hat{\boldsymbol{\Phi}}, \hat{\boldsymbol{V}}, \hat{\boldsymbol{G}})\big] = tr(\hat{\boldsymbol{G}}\hat{\boldsymbol{H}}\hat{\boldsymbol{V}}\hat{\boldsymbol{\Phi}}\hat{\boldsymbol{P}}\boldsymbol{R}_d\hat{\boldsymbol{P}}^H\hat{\boldsymbol{\Phi}}^H\hat{\boldsymbol{V}}^H\hat{\boldsymbol{H}}^H\hat{\boldsymbol{G}}^H) - tr(\hat{\boldsymbol{G}}\hat{\boldsymbol{H}}\hat{\boldsymbol{V}}\hat{\boldsymbol{\Phi}}\hat{\boldsymbol{P}}\boldsymbol{R}_d) - tr(\boldsymbol{R}_d\hat{\boldsymbol{P}}^H\hat{\boldsymbol{\Phi}}^H\hat{\boldsymbol{V}}^H\hat{\boldsymbol{H}}^H\hat{\boldsymbol{G}}^H) + tr(\hat{\boldsymbol{G}}\hat{\boldsymbol{R}}_w\hat{\boldsymbol{G}}^H).$$

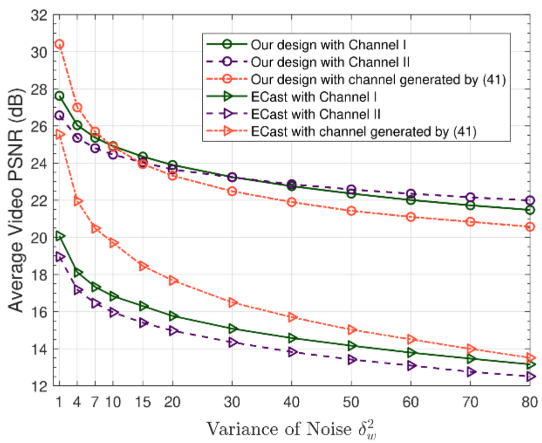
Problem.

$$\min_{\hat{\boldsymbol{V}},\hat{\boldsymbol{\Phi}},\hat{\boldsymbol{P}},\hat{\boldsymbol{G}}} \quad \mathbb{E}_{\boldsymbol{\Xi}}\big[\xi(\hat{\boldsymbol{P}}, \hat{\boldsymbol{\Phi}}, \hat{\boldsymbol{V}}, \hat{\boldsymbol{G}})\big],$$
$$subject\ to \quad tr(\hat{\boldsymbol{\Phi}}\hat{\boldsymbol{P}}\boldsymbol{R}_d\hat{\boldsymbol{P}}^H\hat{\boldsymbol{\Phi}}^H) \le P_0.$$

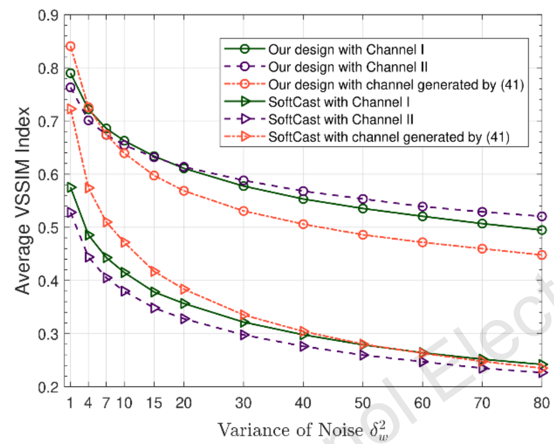
Please find the problem solution in the article paper (Table I and Table II)

Major Results

1. Perfect CSI



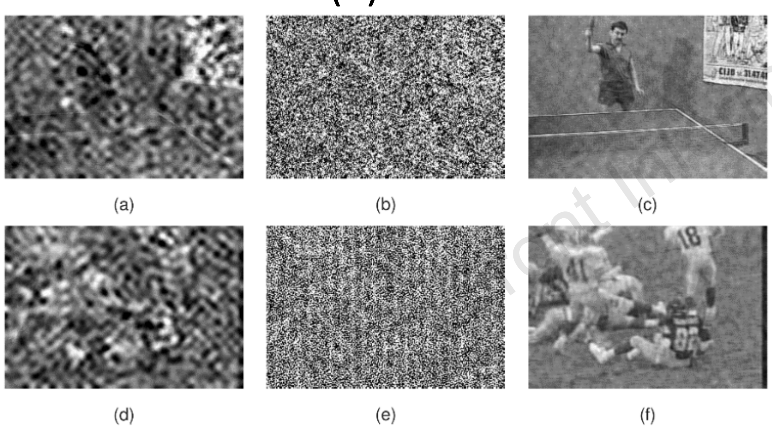
(a)



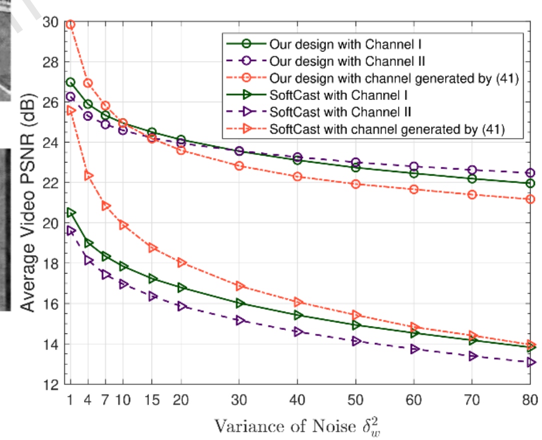
(b)

Performance comparison of the Tennis video:

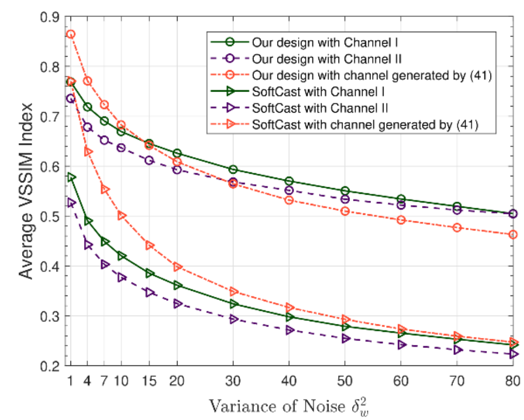
(a) average PSNR
(b) average VSSIM index



Snapshots of the videos reconstructed at the receiver (under Channel II, $\sigma_w^2 = 50$): the 80th frame of the Tennis video reconstructed by SoftCast (a), ECast (b), and our design (c); the 50 th frame of the Football video reconstructed by SoftCast (d), ECast (e), and our design (f)



(a)



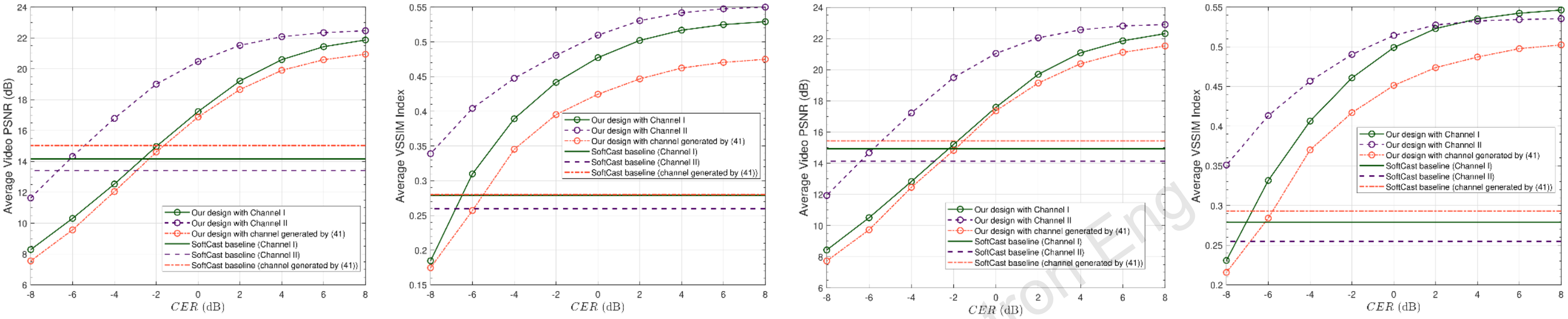
(b)

Performance comparison of the Football video:

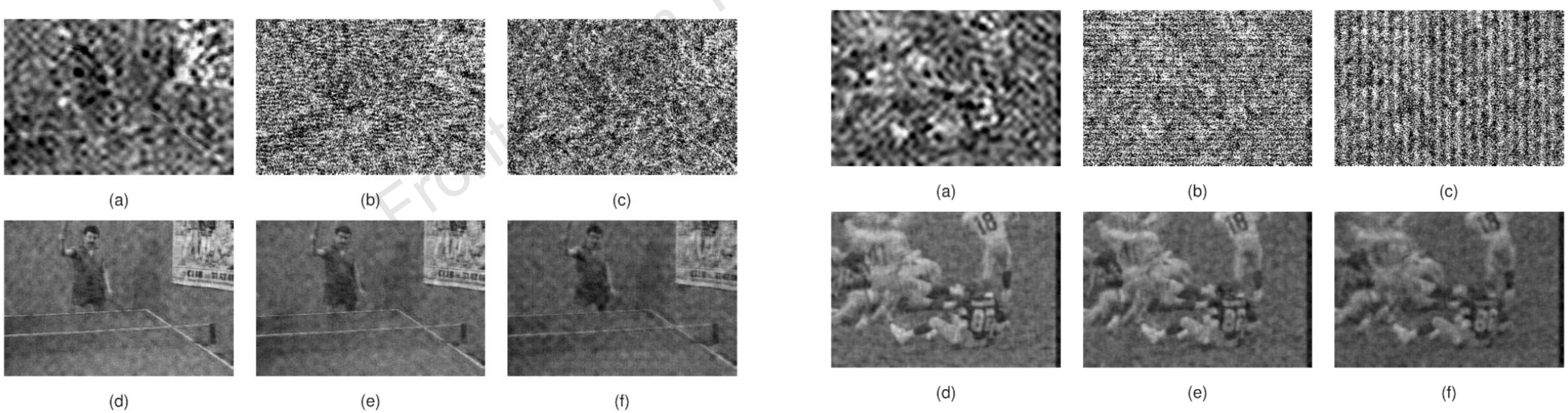
(a) average PSNR, (b)average VSSIM index

Major Results

2. Imperfect CSI



Performance comparison of the Tennis (left two)/ Football (right two) video between SoftCast and our design with imperfect channel state information ($\sigma_w^2 = 50$)



Direct-vision comparison with imperfect channel state information: snapshots of the Tennis (left 6) / Football (right 6) video reconstructed at the receiver (under Channel II and $\sigma_w^2 = 50$) by SoftCast (a), ECast with CER= −2 dB (b), ECast with CER = −4 dB (c), our design with CER = −2 dB (d), our design with CER =−4 dB (e), and our design with CER = −6 dB (f)

Conclusions

- We have proposed a new video transceiver over underwater fading channels. The design is first studied based on the perfect CSI case, and is then extended to the case of an imperfect CSI.
- The optimal subcarrier matching orders and power allocation schemes are similar for both cases by theoretical analysis. The experimental results reveal that, by using the CSI, our design outperforms the existing SoftCast and is resistant to channel estimation error.