Physics Inspired CS based Underwater Acoustic Channel Estimation

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Outline

- Introduction
- System Model
- Physics driven Channel Estimation using CS
- Experiments and Results
- Conclusions

Introduction

Objective: Real-time channel tracking for underwater acoustic communications under dynamic sea conditions

Problems: 1) Rapidly fluctuating transients in acoustic channel impulse response

2) Multipath arrivals

3) Surface wave focusing events

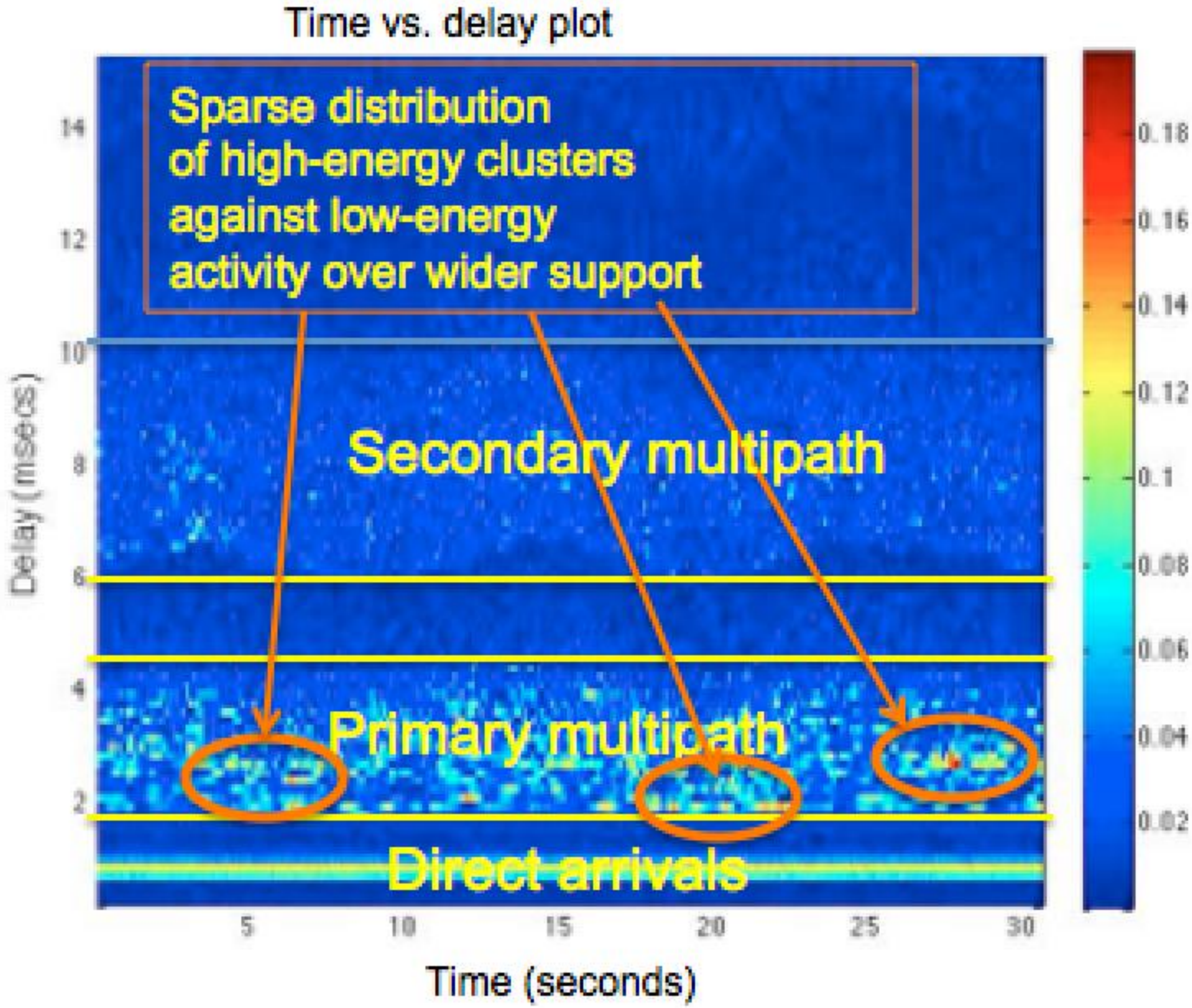


Figure-1: 15 meters depth and 200 meters range over moderate to rough sea conditions

Introduction Cont…

Solution: Sparse sensing techniques may be utilized to track the channel. However, the challenges are:

1) Non-stationary and rapid time-varying delay taps
2) Non-stationary temporal fluctuations of support sparsity
3) Sparse sensing techniques may suppress smaller channel delay taps

Our Prior Work

In one of our previous work (A.Sen Gupta et al., 2015)[1], we proposed the following framework-

- We formulated the underwater channel estimation problem as a spectral sampling problem in the dual domain
- Extended the Delay-Doppler representation
- Designed suitable input signal dictionaries for MIMO transmission and signaling recovery
- Proposed MIMO framework that is similar to *k*-space

1) A. Sen Gupta, N. Ansari, and A. Gupta, “Tracking the underwater acoustic channel using two-dimensional frequency sampling,” IEEE OES International Symposium on Underwater Technology 2015, Feb. 2015, Chennai, India.

System Model

Consider the MIMO[1] framework where the input is:

$$x[i, f_k] = e^{j\frac{2\pi i f_k}{K}},$$

where, $\{f_k\}_{k=0}^{K-1}$ - K delay frequencies and

$\{f_l\}_{l=0}^{L-1}$ - L Doppler frequencies

For the above, the channel output in noise free case is

$$y[i, f_k] = \sum_{k=0}^{K-1} h[i,k] e^{j\frac{2\pi(i-k) f_k}{K}},$$

where, h is K-tap length time varying channel at time i.

1) A. Sen Gupta, N. Ansari, and A. Gupta, "Tracking the underwater acoustic channel using two-dimensional frequency sampling," IEEE OES International Symposium on Underwater Technology 2015, Feb. 2015, Chennai, India.

System Model Cont…

With algebraic manipulations and taking 1-D Fourier transform along time variable i , we get

$$U[f_l, f_k] = \sum_{i=0}^{L-1} \sum_{k=0}^{K-1} h[i,k] e^{-j\frac{2\pi i f_l}{L}} e^{-k\frac{2\pi k f_k}{K}}.$$

Or,

$$\mathbf{U} = \mathbf{F}\mathbf{H} \qquad (1)$$

In noisy scenario:

$$\mathbf{U}_{obs} = \mathbf{F}\mathbf{H} + \mathbf{N}$$

min $||\mathbf{H}||_1$ subject to: $||\mathbf{U}_{obs} - \mathbf{F}\mathbf{H}|| \leq \sigma$

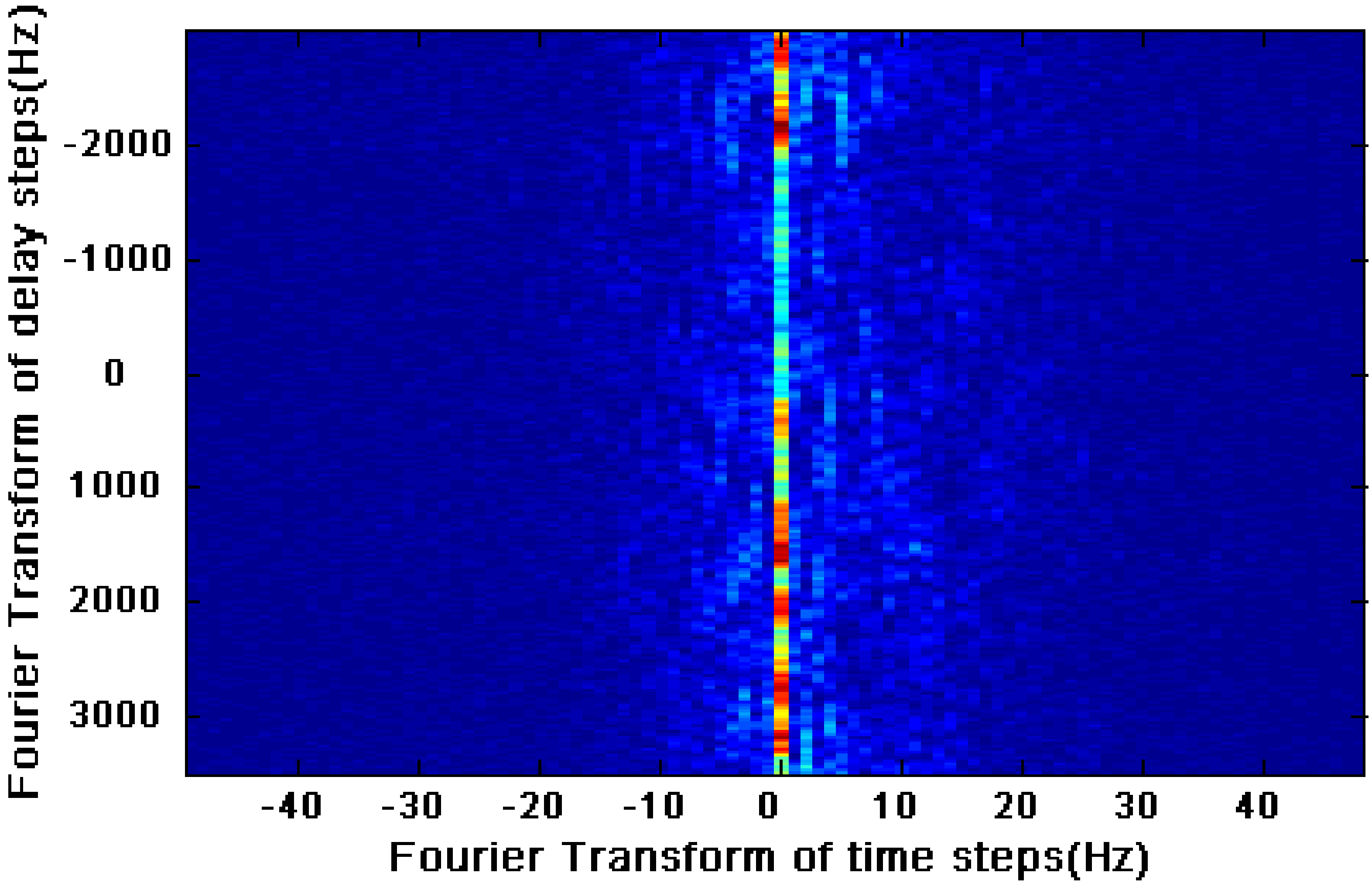


Figure 2: 2-D Fourier Transform of channel shown in Fig.1

Proposed Solution

Track real-time underwater acoustic channel using:

1) Sparsity of the channel in 2-D Fourier domain

2) Knowledge of relative dominance of direct and slowly varying multipath arrivals w.r.t more transient multipath effects and hence, called physics-inspired approach

3) Use Compressive Sensing approach where fewer frequency domain channel measurements are considered

Physics driven Channel Estimation using CS

Basic CS based Channel estimation

Sampling m points of $\mathbf{U}$ using sensing operator Φ

$$\mathbf{u}_{1,obs} = \Phi\mathbf{u} + \mathbf{n}, \qquad (2)$$

(2) can be solved using BPDN[2] as below:

$$\min_{\mathbf{u}} \|\mathbf{u}\|_1 \ \text{ subject to } \ \|\mathbf{u}_{1,obs} - \Phi\mathbf{u}\| < \sigma$$

After obtaining **U**, **H** can be estimated using IFFT on **U**.

2) Chen, Scott Shaobing, David L. Donoho, and Michael A. Saunders. "Atomic decomposition by basis pursuit." *SIAM journal on scientific computing, vol.* 20,pp. 33-61, 1998.

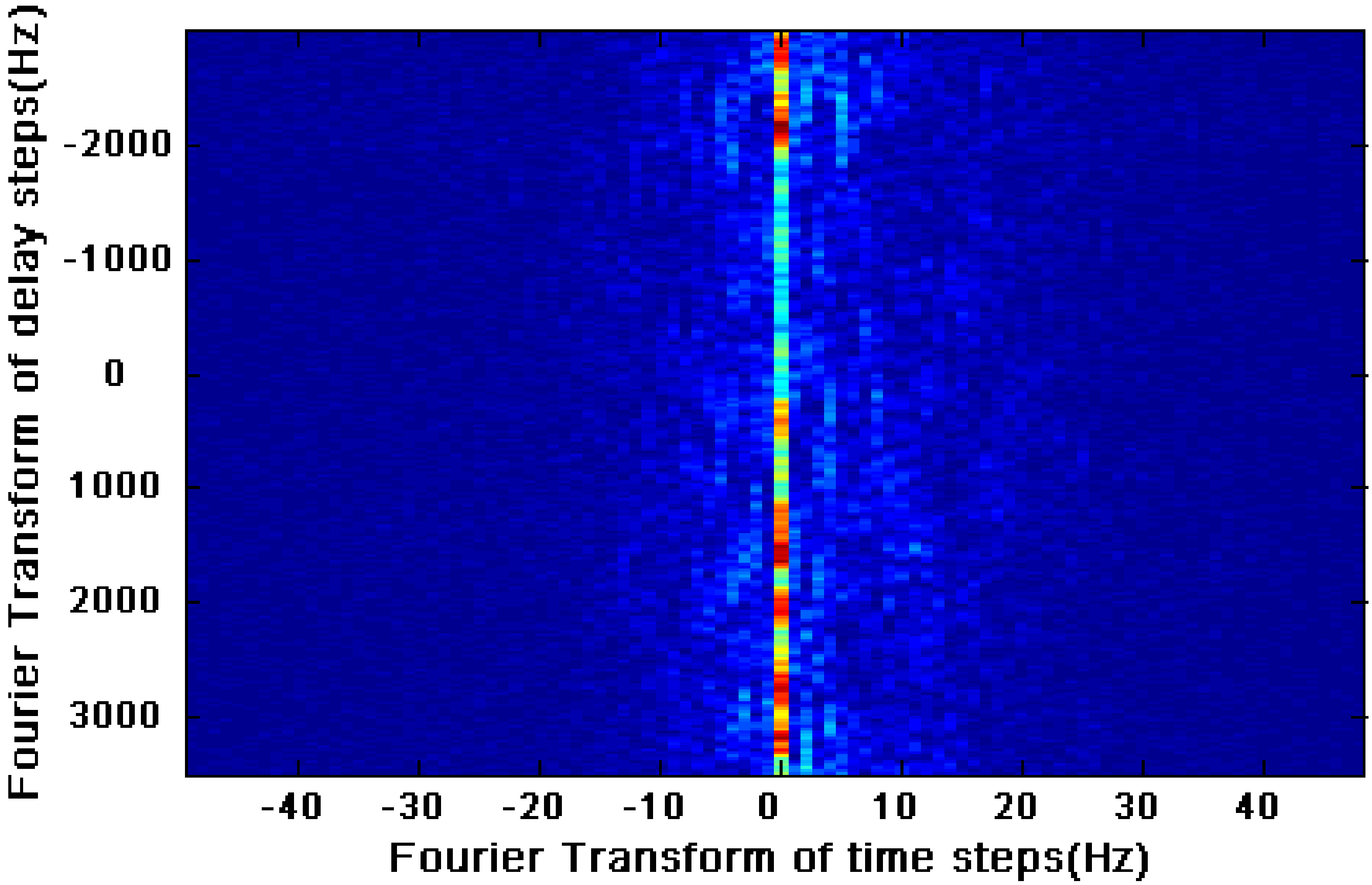


Figure 2: 2-D Fourier Transform of channel shown in Fig.1

Physics driven Channel Estimation using CS Cont...

Physics inspired CS based Channel estimation

If T is the support of $\mathbf{u}$ that contains dominant steady components of the channel, apply sparse sensing on T^c

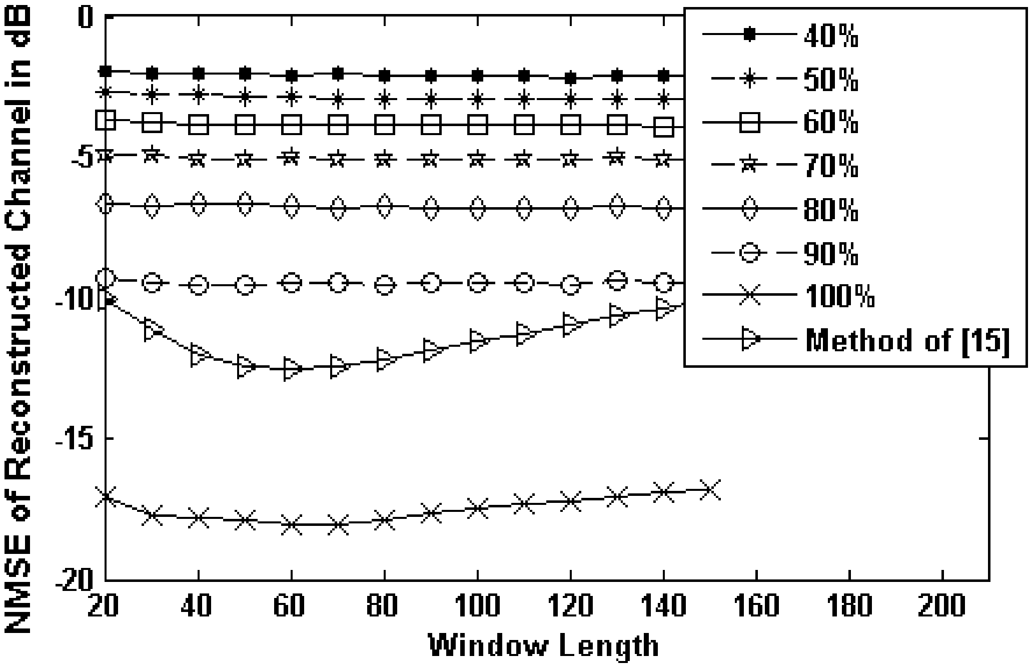
$$\mathbf{u}_{1,obs} = \Phi_R \mathbf{u} + \mathbf{n}, \qquad (3)$$

Φ_R senses m elements in support T^c of $\mathbf{u}$.

(3) can be solved using BPDN as below:

$$\min_{\mathbf{u}} \|\mathbf{u}\|_1 \text{ subject to } \|\mathbf{u}_{1,obs} - \Phi_R \mathbf{u}\| < \sigma$$

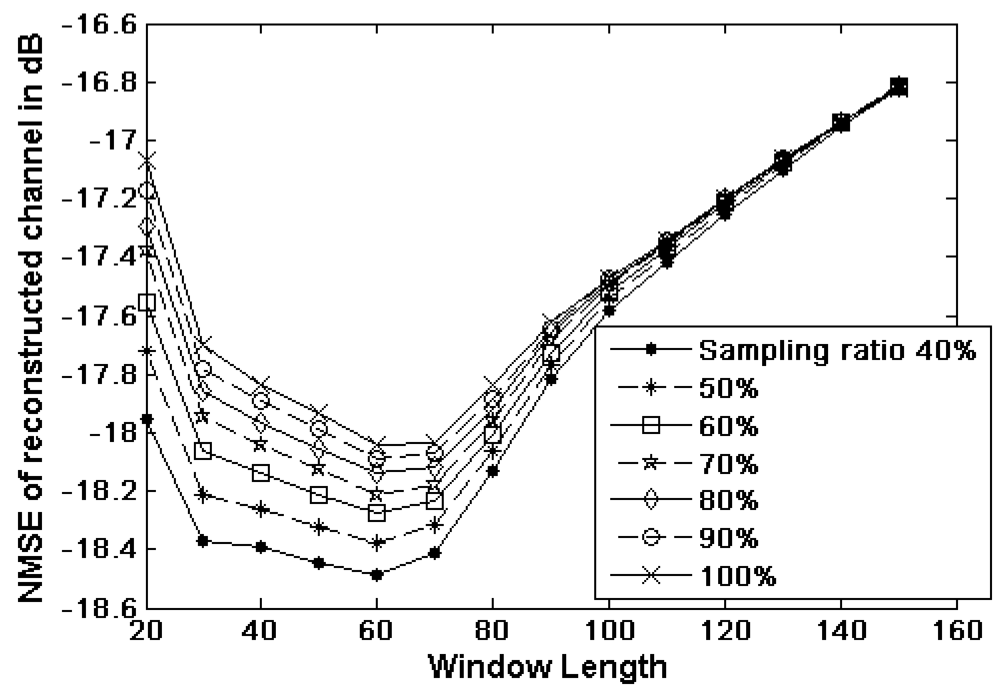
Results

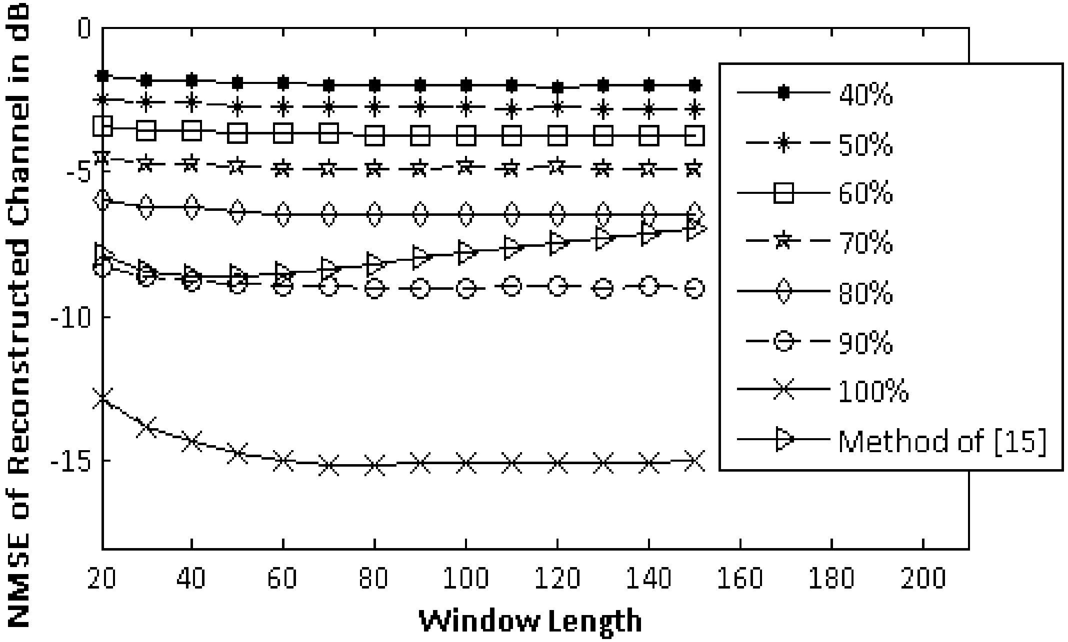


With noisy channel of SNR =10 dB

Physics inspired CS

Basic CS

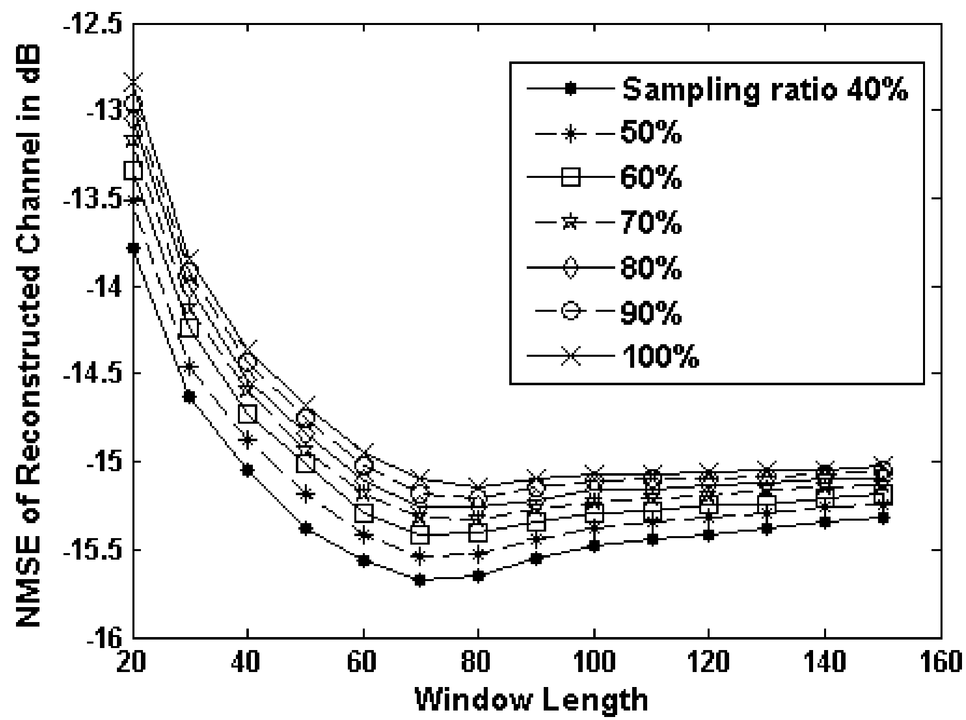




With noisy channel of SNR =5 dB

Physics inspired CS

Basic CS



Conclusion

- Proposed method for underwater acoustic channel estimation
- Knowledge of dominant and relatively steady components of the channel is used
- Channel sparsity in 2-D Fourier domain is harnessed with prior information on the support

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2) W. Li and J. C. Preisig, “Estimation of rapidly time-varying sparse channels,” IEEE J. Ocean. Eng., vol. 32, pp. 927–939, Oct. 2007.

3) A. Sen Gupta and J. Preisig, “A geometric mixed norm approach to shallow water acoustic channel estimation and tracking,” Elsevier J. in Phy. Comm., Spl. Iss. Compressive Sensing in Comm., vol. 5, no. 2, pp. 119–128, June 2012.

4) A. Sen Gupta, J. Preisig, “Adaptive sparse optimization for coherent and quasi-stationary problems using context-based constraints,” Proc. ICASSP, Kyoto, Japan, March 2012.

5) A. Sen Gupta, “Time-frequency localization issues in the context of sparse process modeling”, Proceedings of ICA 2013, Montreal, June 1-5, 2013.

6) J. Preisig, G. Deane, ”Surface wave focusing and acoustic communications in the surf zone,” J. Acoust. Soc. Am. vol. 116, pp. 2067–2080, 2004.

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Thank You