Normalised multi-stage clustering equaliser for underwater acoustic channels

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Overview

- Wireless systems-ubiquitous in everyday life.
- Target-enhance the admissible data rate and hence capacity of the link.
- 3 techniques-a) Equalisation b) Diversity c) Channel Coding.
- Focus of this talk - Equalisation over underwater acoustic channels.
- Underwater acoustic channels-found in environmental monitoring, exploration, military missions [Otnes et al., 2012], leisure and marine research, oceanography and defence [Chitre et al., 2008].
- Typically difficult to transmit data reliably in underwater acoustic channels due to time varying impulse response.

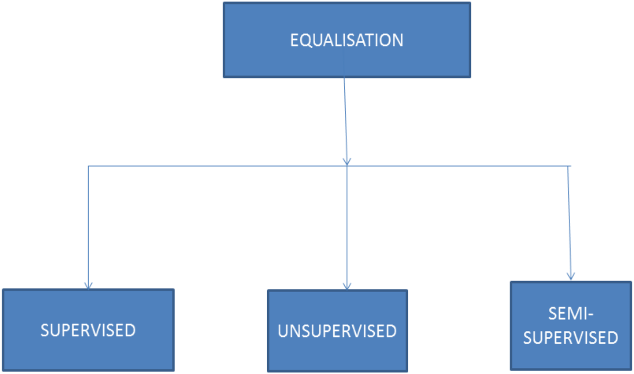
Equalisation

- Dispersive channels cause phenomenon called pulse broadening (or ISI).
- Any technique that minimises ISI is called equalisation.
- Channel equalisation is the process of estimation of inverse transfer function of channel.
- Equalisation can be supervised, unsupervised and semi-supervised.
- In this work, we consider adaptive linear unsupervised equalisers.

Types of Inference

- Equalisation is a technique of inferring the correct labels/symbols of incoming data.
- Inference-supervised, unsupervised and semi-supervised.
- Supervised-full knowledge of labels.
- Semi-supervised-partial knowledge of labels.
- Unsupervised-labels unknown.
- Focus of this talk-unsupervised channel equalisation.

Classification of Equalisers



Review of blind equalisation algorithms

- Seminal works-Constant Modulus Algorithm (CMA) [Treichler and Agee, 1983], multi-stage clustering equaliser [Chen et al., 1995], multi-modulus algorithm [Yang et al., 1997] and square contour algorithm (SCA) [Thaiupathump and Kassam, 2003].
- Works on property restoral techniques.
- CMA-works for constant envelop signals like FM, BPSK etc.
- CMA-Arbitrary phase offset.
- MMA-Phase splitting version of CMA. However has chances of 45 degrees phase offset.
- SCA-no phase rotation but slow convergence.

Review of blind equalisation algorithms

- Independently proposed seminal algorithm [Chen et al., 1995]-multi-stage clustering equaliser based on hierarchical clustering.
- No phase rotation problem.
- Phase splitting version of multi-stage clustering equaliser-improved multi-stage clustering equaliser [Mitra et al., 2011].

Normalised Adaptive Filtering

- Divide regressors by trace of instantaneous covariance matrix.
- Results in faster convergence [Haykin, 2007].
- Sometimes a small number added-to prevent overshoot.
- Paradigms from normalised adaptive filtering borrowed in channel equalisation in [Yin-bing et al., 2010] for CMA based approach.
- IMSC has been found to be better than CMA based approaches in recent work [Mitra et al., 2011].
- Focus-Adapt the normalised filtering approach based on IMSC for impulsive noise.

System Model

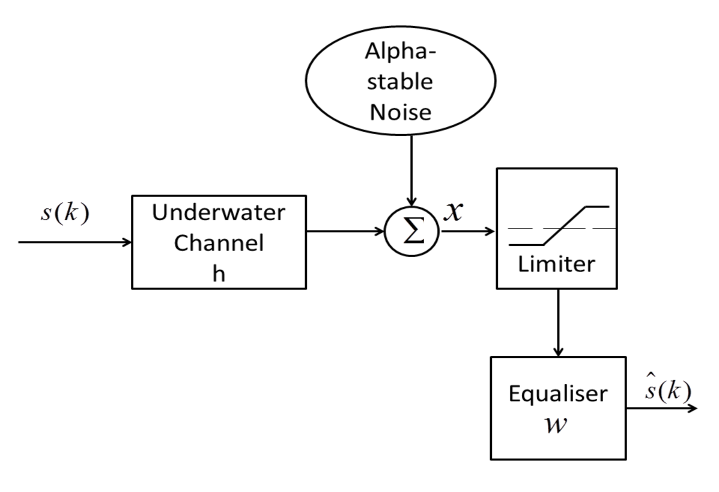


Figure: System Model

System Model

- The system model assumed is depicted.
- $s(k)$ is the input symbol.
- h is the underwater channel.
- w being the equaliser weights.
- $\hat{s}(k)$ is estimated symbol at the output of the equaliser.

Review of IMSC

- Phase-splitting version of [Chen et al., 1995].
- $J_R(k) = \sum_{j=1}^{Q} \exp\left(\frac{-(y_R(k)-\mu_{Rj})^2}{2\rho}\right)$.
- $J_I(k) = \sum_{j=1}^{Q} \exp\left(\frac{-(y_I(k)-\mu_{Ij})^2}{2\rho}\right)$.
-
$$\mathbf{w}_R(k+1) = \mathbf{w}_R(k) + \eta \nabla_{\mathbf{w}_R} J_R(k) \quad (1)$$

and

$$\mathbf{w}_I(k+1) = \mathbf{w}_I(k) + \eta \nabla_{\mathbf{w}_I} J_I(k) \quad (2)$$

Motivation

Choice of criterion for equaliser adaptation in non-linear channels

- Unsupervised equalisers exhibit slow convergence.
- Fast convergence is an important issue in underwater acoustic channels [Yin-bing et al., 2010].
- Normalised adaptive filtering yields faster convergence [Yin-bing et al., 2010].
- IMSC gives faster convergence than other blind equalisation algorithms [Mitra et al., 2011] over fading channels but found to converge slowly in underwater acoustic channels.
- Underwater acoustic communication-profound applciations in environmental monitoring, exploration, military missions [Otnes et al., 2012], leisure and marine research, oceanography and defence [Chitre et al., 2008].
- Solution-Propose normalised IMSC for faster convergence.

Normalised IMSC

- We seek to solve the following optimisation problem:

$$\begin{aligned} \underset{\mathbf{w}_R(k+1)}{\text{minimise}} \quad & \frac{\eta}{2}\|\mathbf{w}_R(k+1) - \mathbf{w}_R(k)\|_2^2 \\ \text{subject to} \quad & J_R = (1-\epsilon) \\ & \epsilon \rightarrow 0 \end{aligned}$$

- Forming the Lagrangian Λ,

$$\Lambda(\mathbf{w}_R, \lambda) = \frac{\eta}{2}\|\mathbf{w}_R(k+1) - \mathbf{w}_R(k)\|_2^2 - \lambda(J_R(k) - (1-\epsilon)) \qquad (3)$$

- Solving for $\mathbf{w}_R$, we take gradient with respect to $\mathbf{w}_R$ as follows:

$$\nabla_{\mathbf{w}_R}\Lambda(\mathbf{w}_R, \lambda) = 0 \qquad (4)$$

$$\implies \eta\mathbf{w}_R(k+1) - \eta\mathbf{w}_R(k) - \lambda e^R_{IMSC}(k)\mathbf{x} = 0$$

$$\implies \eta\mathbf{w}_R(k+1) = \eta\mathbf{w}_R(k) + \lambda e^R_{IMSC}(k)\mathbf{x}$$

Normalised IMSC

- Now solving for λ we assume ζ-convergence of the weights and hence the output estimates,

$$\eta|y_R(k+1) - y_R(k)| = \lambda|e^R_{IMSC}(k)|\|\mathbf{x}\|_2^2 \tag{5}$$

- Hence,

$$\lambda = \Gamma\frac{\eta}{\|\mathbf{x}\|_2^2} \tag{6}$$

where,

$$\Gamma = \frac{|y_R(k+1) - y_R(k)|}{|e^R_{IMSC}(k)|} \rightarrow 1 \tag{7}$$

as at convergence they both are very small, and lie to right hand limit of zero. Thus, the adaptation equation for the proposed normalised-IMSC is given as:

$$\mathbf{w}_R(k+1) = \mathbf{w}_R(k) + \lambda e^R_{IMSC}(k)\mathbf{x} \tag{8}$$

where,

$$\lambda = \frac{\eta}{\|\mathbf{x}\|_2^2} \tag{9}$$

Normalised IMSC

- A small penalty term κ may be added to the denominator to avoid misconvergence, as in common normalised adaptive filtering based approaches [Haykin and Moher, 2004].

$$\lambda = \frac{\eta}{\kappa + \|\mathbf{x}\|_2^2} \tag{10}$$

- The λ for imaginary part may be found out similarly and will equal $\frac{\eta}{\kappa+\|\mathbf{x}\|_2^2}$.
- As gradient descent directions are closed under scaling a constant [Boyd and Vandenberghe, 2004], we adapt as follows till convergence:

$$\mathbf{w}_R(k+1) = \mathbf{w}_R(k) + \eta e^R_{IMSC}(k)\frac{\mathbf{x}}{\kappa + \|\mathbf{x}\|_2^2} \tag{11}$$

$$\mathbf{w}_I(k+1) = \mathbf{w}_I(k) + \eta e^I_{IMSC}(k)\frac{\mathbf{x}}{\kappa + \|\mathbf{x}\|_2^2}$$

Simulations

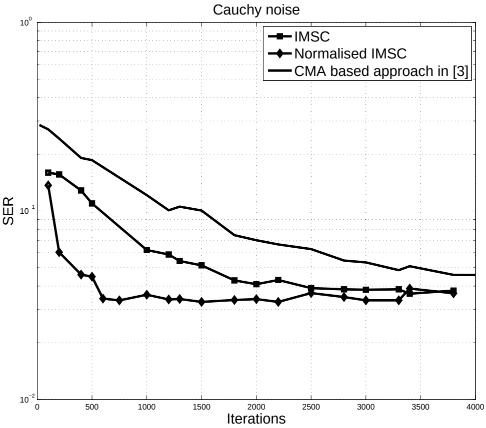


Figure: Convergence plot comparison in first underwater acoustic channel (a) with impulse response given by [0.3132,-0.1040,0.8908,0.3143] [Yin-bing et al., 2010] at SNR of 22dB

Simulations

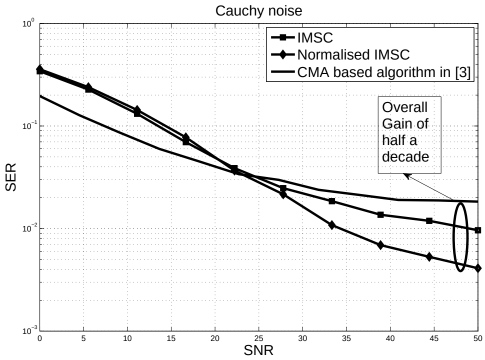


Figure: SER vs SNR comparison in first underwater acoustic channel (a) with impulse response given by [0.3132,-0.1040,0.8908,0.3143] [Yin-bing et al., 2010]

Simulations

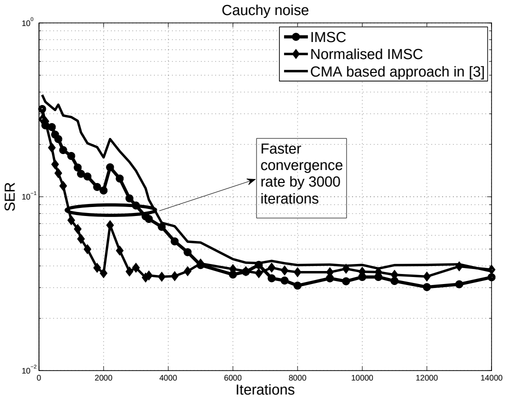


Figure: Convergence comparison in second underwater acoustic channel (b) with impulse response given by [0.5849,-1,0.2608,-0.1336,0.0740,-0.0394,0.0183,-0.0059,-0.0006,0.0031] [Yin-bing et al., 2010] at SNR of 22dB

Simulations

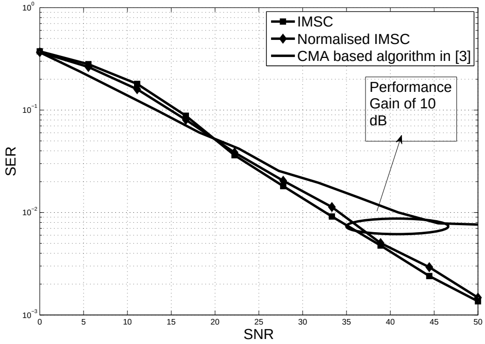


Figure: SER vs SNR Comparison in second underwater acoustic channel (b) with impulse response given by [0.5849,-1,0.2608,-0.1336,0.0740,-0.0394,0.0183,-0.0059,-0.0006,0.0031] in [Yin-bing et al., 2010]

Conclusion

- A normalised-IMSC based blind equaliser is proposed for underwater acoustic communication channels.
- The proposed algorithm is observed to have faster convergence than IMSC and the CMA based algorithm..
- A lower SER is also observed for impulsive noise effected underwater acoustic communication channel for SNR greater than 20-25dBs.
- Convergence analysis was carried out and the proposed algorithm was analytically proven to be close to the optimal solution at a given iteration.
- Hence, the proposed algorithm is a viable solution to equalise an underwater acoustic channels in the presence of impulsive noise.

Boyd, S. P. and Vandenberghe, L. (2004).
Convex optimization.
Cambridge university press.

Chen, S., McLaughlin, S., Grant, P. M., and Mulgrew, B. (1995).
Multi-stage blind clustering equaliser.
Communications, IEEE Transactions on, 43(234):701–705.

Chitre, M., Shahabudeen, S., and Stojanovic, M. (2008).
Underwater acoustic communications and networking: Recent advances and future challenges.
Marine technology society journal, 42(1):103–116.

Haykin, S. S. (2007).
Adaptive filter theory.
Pearson Education India.

Haykin, S. S. and Moher, M. (2004).
Modern wireless communication.

Prentice Hall.

Mitra, R., Singh, S., and Mishra, A. (2011).
Improved multi-stage clustering-based blind equalisation.
IET Communications, 5(9):1255–1261.

Otnes, R., Asterjadhi, A., Casari, P., Goetz, M., Husøy, T., Nissen, I., Rimstad, K., van Walree, P., and Zorzi, M. (2012).
Underwater acoustic networking techniques.
Springer Science & Business Media.

Thaiupathump, T. and Kassam, S. (2003).
Square contour algorithm: a new algorithm for blind equalization and carrier phase recovery.

Treichler, J. and Agee, B. (1983).
A new approach to multipath correction of constant modulus signals.

Acoustics, Speech and Signal Processing, IEEE Transactions on, 31(2):459–472.

Yang, J., Werner, J.-J., and Dumont, G. (1997).
The multimodulus blind equalization algorithm.
In *Digital Signal Processing Proceedings, 1997. DSP 97., 1997 13th International Conference on*, volume 1, pages 127–130. IEEE.

Yin-bing, Z., Jun-wei, Z., Ye-cai, G., and Jin-ming, L. (2010).
A constant modulus algorithm for blind equalization in α-stable noise.
Applied Acoustics, 71(7):653–660.

Thank You

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