

SVR-based Blind Equalization on HF Channels with a Doppler Spread

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Abstract—A transmission signal through a high-frequency (HF) channel is usually reflected by the ionospheric layers and become a multipath signal, resulting in inter-symbol interference (ISI). To remove ISI, a receiver recovers the multipath-faded signal by using channel equalization. Among various channel equalization methods, blind equalization that does not use training sequences draws an interest because it may increase bandwidth efficiency. The HF signal needs to be equalized with a small number of symbols due to a Doppler spread. Therefore, to equalize the HF channel signal, a batch method based on support vector regression (SVR) can be used. In this respect, we applied an SVR-based batch blind equalization to HF channels and then analyzed its performance.

Keywords—blind equalization, support vector regression, high frequency channel

I. INTRODUCTION

In a high frequency (HF) band digital communication channel, the signal reception performance is deteriorated due to inter-symbol interference (ISI), which makes it hard to recover the signal and causes a symbol error. To remove ISI, various channel equalization techniques have been studied recently [1],[2].

Channel equalization method is divided into two types depending on whether a training sequence is used or not. A representative method using a training sequences is the least mean squared (LMS) algorithm, which is easy to implement and widely used due to its low complexity [3]. However, using a training sequence reduces the transmission rate. Therefore, to efficiently transmit a signal, blind equalization methods that do not use a training sequence have been studied [4].

Blind equalization can be divided into online method and batch algorithm. The online blind algorithms are based on stochastic gradient descent (SGD) minimization of a cost function. The most representative method is constant modulus

algorithm (CMA) [5]. On the other hand, the batch algorithms use a block of data and iteratively minimize a cost function based on support vector regression (SVR) or cumulant [6]. Batch algorithm can achieve good equalization performance by using fewer symbols than online one [7].

In the HF channel with a Doppler spread, since the channel changes with time, the received signal should be equalized with a small number of symbols. Therefore, the batch method is better than online ones. In this paper, the equalization performance of the HF channel in the mid-latitude region is analyzed by using the SVR-based batch equalization algorithm according to the channel conditions.

II. PROBLEM FORMULATION

The overall block diagram of the blind equalization including the signal process is shown in Fig. 1. We consider baseband representation of the digital communication system. A sequence of independent and identically distributed (i.i.d) symbols $s(k)$ is sent through a channel with coefficients $h(k)$. The resulting channel output can be expressed as

$$x(k) = \sum_{n=0}^{L-1} h(n)s(k-n) + v(k), \quad (1)$$

where $v(k)$ is an additive white Gaussian noise (AWGN) and L is channel coefficient length.

The objective of blind equalization is to remove the ISI caused by the channel. The equalization output can be expressed as

$$y(k) = \sum_{n=0}^{M-1} w(n)x(k-n) = \mathbf{x}^T \mathbf{w}, \quad (2)$$

where \mathbf{w} is the vector of filter coefficients and M is filter coefficient length.

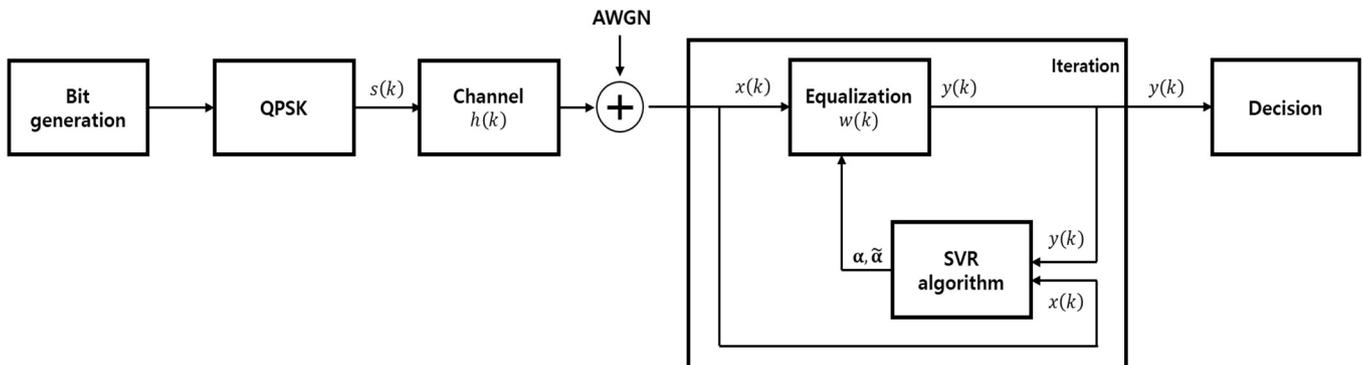


Fig. 1. Block diagram of signal transmission/reception including blind equalization.

A. SVR-based Batch Blind Equalization

When the data block size is N , batch equalization minimizes the following SVR-based cost function that exploits the constant modulus (CM) property of the signal [8].

$$J(\mathbf{w}) = \frac{1}{2} \|\mathbf{w}\|^2 + C \sum_{i=1}^N |1 - (\mathbf{w}^T \mathbf{x}_i)^2|_\epsilon \quad (3)$$

where C is penalty value, $\mathbf{x}_i = (x_i, \dots, x_{i-M+1})^T$, and

$$|1 - (\mathbf{w}^T \mathbf{x}_i)^2|_\epsilon = \max\{0, |1 - (\mathbf{w}^T \mathbf{x}_i)^2| - \epsilon\} \quad (4)$$

the so-called Vapnik's ϵ -insensitive loss function.

If there are training error, by using a set of positive slack variables ξ_i and $\tilde{\xi}_i$, the optimization equation can be expressed as: To minimize

$$L(\mathbf{w}, \boldsymbol{\xi}, \tilde{\boldsymbol{\xi}}) = \frac{1}{2} \|\mathbf{w}\|^2 + C \sum_{i=1}^N (\xi_i + \tilde{\xi}_i) \quad (5)$$

subject to

$$(\mathbf{w}^T \mathbf{x}_i)^2 - 1 \leq \epsilon + \xi_i$$

$$1 - (\mathbf{w}^T \mathbf{x}_i)^2 \leq \epsilon + \tilde{\xi}_i$$

$$\xi_i, \tilde{\xi}_i \geq 0$$

for all $i = 1, 2, \dots, N$.

To transform the quadratic inequality of the constraint into linear one and make it a quadratic programming (QP) problem, we can use

$$y_i = \mathbf{w}^T \mathbf{x}_i. \quad (6)$$

If the transformed optimization problem is solved through Lagrange dual, the solution is as follows.

$$\mathbf{w}^* = \sum_{i=1}^N (\tilde{\alpha} - \alpha) y_i \mathbf{x}_i \quad (7)$$

where α and $\tilde{\alpha}$ are Lagrange multipliers, and can be obtained by minimizing the following quadratic form:

$$\begin{aligned} W(\boldsymbol{\alpha}, \tilde{\boldsymbol{\alpha}}) = & \epsilon \sum_{i=1}^N (\alpha_i + \tilde{\alpha}_i) - \sum_{i=1}^N (\alpha_i - \tilde{\alpha}_i) \\ & + \frac{1}{2} \sum_{i,j=1}^N (\alpha_i - \tilde{\alpha}_i)(\alpha_j - \tilde{\alpha}_j)(y_i y_j) \langle \mathbf{x}_i, \mathbf{x}_j \rangle \end{aligned} \quad (8)$$

B. HF channel modeling

The HF channel uses a frequency band of 3 to 30 MHz. Since long-distance communication can be performed with a low power, the HF channel is widely used despite the poor communication channel.

The HF channel signal is reflected by the ionosphere of the atmosphere and can propagate far away by repeated reflections of the ionosphere and the Earth's surface. Because of these advantages, HF channels are widely used in international broadcasting or amateur radio. The ionosphere is divided according to the distribution of ions, and the channel state varies according to various conditions such as weather and latitude. HF channels generally have Doppler spread due

Table 1. High frequency channel parameters in mid latitude regions according to channel conditions.

Parameters	Channel Condition		
	<i>Quiet</i>	<i>Moderate</i>	<i>Disturbed</i>
Differential time delay	0.5 ms	1 ms	2 ms
Doppler spread	0.1 Hz	0.5 Hz	1 Hz

to fine tremor of ionospheric ions, and each multipath signal has a Rayleigh distribution.

Channel parameters according and channel conditions are modeled as representative values in ITU-R (international telecommunication union - radiocommunication) F.1487 [9]. The mid-latitude HF channel parameters according to the channel conditions are summarized in Table 1.

III. SIMULATION RESULT

In simulation, we use $C = 1, \epsilon = 0.01$. The modulation scheme is quadrature phase shift keying (QPSK). The number of equalizer taps is $M = 17$ and signal-to-noise ratio (SNR) is 30 dB. The central tap of equalizer is initialized to 1, and the remaining equalizer taps are initialized to 0.

The performance evaluation criteria are the residual ISI and probability of convergence. The residual ISI is defined as

$$\text{ISI} = 10 \log_{10} \frac{\sum_k |\theta_k|^2 - \max_k |\theta_k|^2}{\max_k |\theta_k|^2} \quad (9)$$

where $\theta = \mathbf{h} * \mathbf{w}$. In simulation, convergence means that the final residual ISI value is less than -5 dB.

Fig. 2 shows the convergence probability according to the data block size. When the channel condition is "Quiet," it converges to 100% when the data block size is 200 or more. When the channel condition is "Moderate," it almost converges to 100% at data block size 200. However, when it is larger than 200, the convergence probability is reduced to 96% because the channel is time-varying. When the channel condition is "Disturbed," it converge to 94% when data block sized is 200. The better the channel condition, the higher the convergence probability.

Fig. 3 shows the residual ISI according to the data block size. When the channel condition is "Quiet," the residual ISI

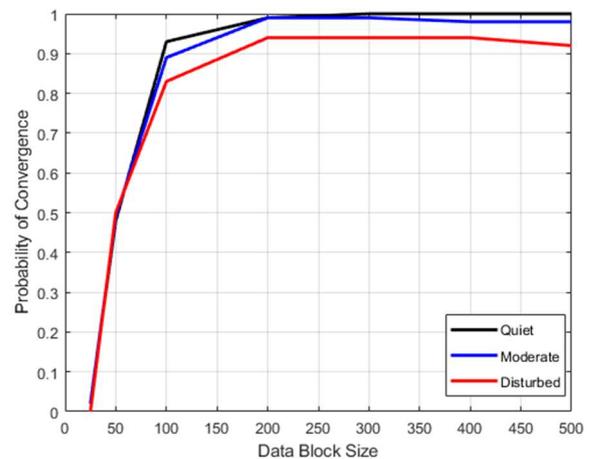


Fig. 2. Probability of convergence according to data block size using SVR-based blind equalization

decreases as the data block size increases, and it converges to about -23 dB. However, When the channel condition is “Moderate” or “Disturbed,” the residual ISI decreases and then increases again as the data block size increases. This is because, as the Doppler spread increases, the channel changes rapidly. When the channel condition is “Moderate” and block data size is 200 or 300, the residual ISI is -17 dB and the performance is the best. When the channel condition is “Disturbed” and block data size is 200, the residual ISI is -13 dB and the performance is the best.

IV. CONCLUSION

In this paper, SVR-based blind equalization performance is analyzed for the HF channel in ITU-R F.1487. In the case of a fixed channel, the larger the data block size, the better the equalization performance. However, In the case of a time-varying channel, residual ISI decreases at first but then increases when the block size increases. In simulation, when the channel condition is “Quiet,” as the data block size increases, the equalization performance gets better. However, when the channel condition is “Moderate” or “Disturbed,” we need to find an appropriate batch size by taking a trade-off.

ACKNOWLEDGMENT

This work was supported by the National Research Foundation of Korea(NRF) grant funded by the Korea government(MSIT) (No. 2021R1F1A1060025).

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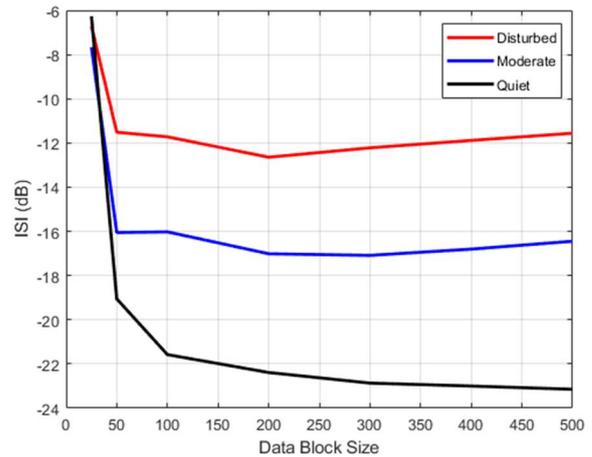


Fig. 3. Residual ISI according to data block size using SVR-based blind equalization

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