SNR Estimation Algorithm Based on Pilot Symbols for DFT-Spread OFDM Systems over Underwater Acoustic Channels

SHEN Weijie1, SUN Haixin2,*, CHENG En3, ZHANG Yonghuai4

1, 3, 4 Key Laboratory of Underwater Acoustic Communication and Marine Information Technology (Xiamen University), Ministry of Education, P.R.C
Xiamen 361005, China

2, * Corresponding Author
Department of Communication Engineering, Xiamen University, Xiamen
361005, China, hxsun@xmu.edu.cn
doi:10.4156/jcit.vol6.issue2.20

Abstract

Effective and low complexity methods for signal to noise ratio (SNR) estimation remain a challenge to underwater acoustic communication due to the ocean environment characteristic which can be summarized as simultaneously severe frequency selectivity and fast-time variability. In this study, a novel SNR estimation method was proposed by using only one training symbols in the pilots and applied to DFT-Spread OFDM transmission system over underwater acoustic channels. The method will be effective against frequency selectivity and fast time varying of underwater acoustic channels. Simulations showed technically feasibility of our proposal. Further, a systematic investigation in the shallow water near Xiamen demonstrated that single training symbol based SNR estimator would be applicable for DFT-Spread OFDM system over underwater acoustic channels.

Keywords: DFT-Spread OFDM, Underwater Acoustic Communication, SNR Estimation

1. Introduction

Signal to noise ratio is commonly defined as the power ratio of the desired signal to the noise and has been accepted as a standard that measure the signal quality of transmission links. Effective and low complexity methods for SNR estimation are essential to modern wireless transmission systems since the operations of many key techniques, such as soft decoding procedures, adaptive coding and modulation, mobile assisted handoff algorithms and channel estimation [1]-[4], are strongly dependent on the accurate SNR estimation.

There are many available SNR estimation algorithms in the literature. Up to now, most of the proposed algorithms are related to signal carrier transmission [5]-[7]. In [5], a detailed comparison of various algorithms for digital communication channels is presented to identify the “best” estimator. Only in recent years, attention has been focused on the SNR estimation for multi-carrier modulation systems [8]-[12]. By reusing the synchronization pilots, Milan and Rudolf proposed a novel SNR estimator for wireless OFDM systems [8]. It does not require any knowledge of the transmitted symbols on loaded subcarriers but only the arrangement of loaded and null subcarriers at the receiver. However, its performance degrades greatly when the pilot sub-carriers are located in severe frequency-selective sub-channels. In allusion to this instance, G.L. Ren etc. proposed a SNR estimator which is robust to frequency-selectivity and suitable for the terminal with a low speed for OFDM systems [9]. The samples of two adjacent pilot symbols with the same structure are employed to estimate SNR. However, this algorithm is very sensitive to channel’s fast-time variability.

Accurate and low complexity SNR estimation methods remain a challenge to underwater acoustic communication since the ocean environment characteristics drive the complexity of underwater acoustic communications systems which can be summarized as simultaneously excessive multipath delay spread and fast-time variability [12]. In order to improve the performance, we propose a novel SNR estimation method for underwater acoustic DFT-Spread OFDM transmission system. By using only one training symbol in the pilots, the noise variance is estimated, and the second order moment of the received signals in the packet are employed to estimate the signal plus noise power. The SNRs on the sub-channels and the average SNR of the packet can be estimated by the proposed method. On one hand, it will be effective against frequency selectivity for the SNR estimation is implemented by all
SNR Estimation Algorithm Based on Pilot Symbols for DFT-Spread OFDM Systems over Underwater Acoustic Channels
SHEN Weijie, SUN Haixin2, CHENG En, ZHANG Yonghuai
Journal of Convergence Information Technology, Volume 6, Number 2. February 2011

Subcarriers. On the other hand, it has a good effect of confronting with fast time varying because SNR estimation is implemented with only one pilot. As can be seen from the experiment, the method is robust to underwater acoustic communication systems.

The rest of the paper is organized as follows. In the next Section, a previous reported SNR estimator was applied to DFT-Spread OFDM system, and based on this, a new estimator was proposed. Simulation and Experiment results in the experimental pool of Xiamen University were performed in section III, as well as the results in shallow water near Xiamen, before the discussion in section IV.

2. SNR estimation methods for DFT-Spread OFDM system

In recent years, several SNR estimation methods have been presented by using the samples of pilots in wireless OFDM system. In reference [9], the SNRs on the sub-channels and the average SNR of the packet can all be estimated by using the two adjacent OFDM training symbols with the same structure. The method will be effective against frequency selectivity. Now it is applied to DFT-Spread OFDM system over underwater acoustic channels. However, the algorithm is sensitive to channel’s fast-time variability. Therefore, a new estimator is explored later in this section. The symbols duration for SNR estimation is shorter than coherence time of underwater acoustic channels since SNR estimation is implemented with only one training symbol. The method will be effective against fast time varying of underwater acoustic channels.

2.1. Estimator based on adjacent training symbols

Here adjacent training symbols with the same DFT-Spread OFDM signals are chosen for noise variance estimation. All subcarriers of both symbols are modulated with pilot signals. The number of pilots is \( N_p = N_c \). Here the pilots are the Const Amplitude Zero Auto-Correlation (CAZAC) sequence which will be spread by DFT operation.

\[
C_p = \frac{1}{N_p} FFT(CAZAC)
\]  

(1)

The \( m^{th} \) and \((m + 1)^{th}\) DFT-Spread OFDM training symbols in the pilots can be described as

\[
c(m, n) = c(m + 1, n) = C_p(n)
\]  

(2)

where \( n \) donates the \( n^{th} \) subcarrier in training symbols. Assumed that the channel is slow fading, then

\[
H(m, n) = H(m + 1, n) = H(n)
\]  

(3)

In the above equation, the data \( c(m, n) \) and \( c(m + 1, n) \) are known, and it is often assumed that \( \|c(m, n)\| = 1 \), \( \|c(m + 1, n)\| = 1 \). Let

\[
\Delta Y(m, n) = Y(m, n) - H(k) + w(m, n)\cdot c^*(m, n) = H(k) + w(m, n)
\]

\[
\Delta Y(m + 1, n) = Y(m + 1, n) - H(k) + w(m + 1, n)\cdot c^*(m + 1, n) = H(k) + w(m + 1, n)
\]  

(4)

where \( Y(\cdot) \) is the received signals, \( H(\cdot) \) is impulse response of the channels and \( w(\cdot) \) is the sample of zero-mean complex Gaussian noise process with variance 1. The second order moment of received signals can be described as
where $P_n$ is the power of the signal of the $n^{th}$ sub-channel, $W$ is the noise variance. Thus the SNR on the $n^{th}$ sub-channel is estimated with

$$\hat{\rho}_{av} = \frac{M_{2,n}}{W} - 1$$

### 2.2. A new estimator

In DFT-Spread OFDM systems, transmission is organized in frames. Supposed that the number of valid sub-carriers is $N_c$, and the number of pilots is $N_p = N_c$. Here the pilots are the CAZAC sequence that is the same as the former estimator. The $n^{th}$ subcarrier in $m^{th}$ pilot of DFT-Spread OFDM training symbols can be described as

$$C(m, n) = C_p(n)$$

The received signal is

$$Y(m, n) = c(m, n)H(m, n) + w(m, n)$$

where $n = 1, 2, \cdots, 2l - 1, 2l$. And $H(\cdot)$ is impulse response of the channels and $w(\cdot)$ is the sample of zero-mean complex Gaussian noise process with variance 1. In the same DFT-Spread OFDM symbol, assume that

$$H(m, 2l - 1) = H(m, 2l) = H(l)$$

where $l = 0, 1, \cdots, N / 2 - 1$.

Then we can get

$$Y(m, 2l - 1) = c(m, 2l - 1)H(m, l) + w(m, 2l - 1)$$

$$Y(m, 2l) = c(m, 2l)H(m, l) + w(m, 2l)$$

In the above equation, the data $c(m, 2l - 1)$ and $c(m, 2l)$ are known and it is often assumed that $\|c(m, 2l - 1)\| = \|c(m, 2l)\| = 1$.

$$Y(m, 2l - 1) = Y(m, 2l - 1) + n(m, 2l - 1)H(l) + w(m, 2l - 1)$$

$$Y(m, 2l) = Y(m, 2l) + n(m, 2l)H(l) + w(m, 2l)$$

Consider the following equation:
Therefore, the noise variance can be estimated by

$$W = \frac{1}{2} E \left\{ \| Y(m, 2l-1) - Y'(m, 2l) \|^2 \right\}$$  \hfill (13)

The second order moment of received signals can be described as

$$M_{2,2l-1} = E \left\{ \| Y(m, 2l-1) \|^2 \right\}$$

$$= E \left\{ \| c(m, 2l-1)H(m, 2l-1) \|^2 \right\} + E \left\{ \| w'(m, 2l-1) \|^2 \right\}$$

$$= P_{2l-1} + W$$  \hfill (14)

where $P_{2l-1}$ is the power of the signal of the $(2l-1)^{th}$ sub-channel.

From (13) and (14), the signal power on the $(2l-1)^{th}$ sub-channel can be estimated as

$$P_{2l-1} = M_{2,2l-1} - W$$  \hfill (15)

Thus the SNR on the $n^{th}$ sub-channel is estimated with

$$\hat{\rho}_{2l-1} = \frac{M_{2,2l-1}}{W} - 1$$  \hfill (16)

3. Simulation and experiments

3.1. Simulation

The proposed algorithm is firstly simulated over an AWGN channel in MATLAB. The DFT-Spread OFDM system parameters used in the simulation are indicated in Table I. Suppose that the time synchronization and frequency synchronization are perfect since the aim is to observe SNR estimation performance. The guard interval is chosen to be much longer than the maximum delay spread in order to avoid inter-symbol interference. Simulations are carried out for different input SNR. The results are shown in Fig. 1.

<table>
<thead>
<tr>
<th>Table 1. SYSTEM SPECIFICATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>DFT length</td>
</tr>
<tr>
<td>IFFT length</td>
</tr>
<tr>
<td>Guard interval</td>
</tr>
<tr>
<td>Symbol duration</td>
</tr>
<tr>
<td>Effective bandwidth</td>
</tr>
<tr>
<td>Effective speed</td>
</tr>
</tbody>
</table>
Fig. 1 gives SNR estimation performance of different methods by increasing value of input SNR from 0dB to 15dB in an AWGN channel. As can be seen from the figure, both algorithms can make an accurate SNR estimation. The results are almost the same. When the input SNR is from 2dB to 5dB, the performance of both algorithms is excellent. The estimated SNR is smaller than the input SNR when the input SNR is below 2dB. This is the direct opposite of the situation when the input SNR is over 5dB. The differences of them are smaller than 1dB. That is because the AWGN has a little influence on the signals. Simulations showed technically feasibility of our proposal.

3.2. Shallow water experiments

The experiment was also carried out in the shallow water near Xiamen. System specifications for the experiment are the same as in the simulation. The distance between transmitter and receiver was 840m. And the locations of the transmitter and receiver were about 4 meters under water.

Table II is the SNR estimation performance of the experiment in the real marine underwater acoustic channels. As can be seen from the table, the single training symbol based SNR estimation has better performance than adjacent training symbols based algorithm when applied to the real underwater acoustic channel. In both instances, the average values of SNR estimation are about 7dB (7.0497dB and 7.7709dB respectively). In adjacent training symbols based algorithm, the maximum value of estimated SNR even reaches 9.4976dB while the minimum value is only 3.6375dB. Its variance is 18.0619. In single training symbol based SNR estimation, the values of SNR estimation are between 7.83dB and 7.7195dB. The variance is only 0.0077 which is much smaller than that of adjacent training symbols based algorithm.

<table>
<thead>
<tr>
<th>Number</th>
<th>Adjacent training symbols based estimator</th>
<th>Single training symbol based estimator</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>7.4926</td>
<td>7.8300</td>
</tr>
<tr>
<td>2</td>
<td>9.4976</td>
<td>7.7887</td>
</tr>
<tr>
<td>3</td>
<td>3.6375</td>
<td>7.7368</td>
</tr>
<tr>
<td>4</td>
<td>7.5278</td>
<td>7.7195</td>
</tr>
<tr>
<td>5</td>
<td>7.0931</td>
<td>7.7797</td>
</tr>
<tr>
<td>Average</td>
<td>7.0497</td>
<td>7.7709</td>
</tr>
<tr>
<td>Variance</td>
<td>4.5155</td>
<td>0.0019</td>
</tr>
</tbody>
</table>

In comparison, the performance of adjacent training symbols based algorithm is unstable in the real marine underwater acoustic channels. The difference of estimated SNR between the maximum and minimum values is about 6dB. That is because the channels in the real marine are fast time varying. The estimated channel situations are quite different from the real values. This substitute has a certain effect on the reliability of SNR estimation. Relatively speaking, the performance of single training
symbol based algorithm is much more stable over the real marine underwater acoustic channels.

4. Conclusion

This work presented a novel single training symbol based SNR estimation algorithm, and applied it to underwater acoustic DFT-Spread OFDM system. The proposed algorithm holds three main advantages with respect to SNR estimation. First and foremost, the experiment results in shallow water showed that the single training symbol based SNR estimation could achieve stable performance as comparing with adjacent training symbols based estimator. Besides, the proposed algorithm performed comparable bandwidth efficiency to adjacent training symbols based method. Last but not least, it need not change the frame structure of existing protocol, which is vital for the detection methods that are exploited at the receiver. The study demonstrated that single training symbol based SNR estimation would be applicable for DFT-Spread OFDM system over underwater acoustic channels.

5. Acknowledgments

This work was supported by The National Nature Science Foundation of China under Grants 60672046 and the Natural Science Foundation of Fujian Province, China under Grants 2009J05155. It is also supported by 985 innovation project on information technology of Xiamen University. The authors would like to thank the unknown reviewers for their valuable suggestions and critique.

6. Reference