Performance of Joint Channel Estimation and Spreading Sequence Detection for DSSS Systems

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***Abstract*—To estimate channel response and detect spreading sequence jointly in Direct Sequence Spread Spectrum (DSSS) systems, a turbo-based algorithm was proposed [12]. However, the performance of the proposed algorithm has not been fully investigated for various configurations. Especially, the channel estimation performance has not been evaluated. In this paper, the performance of the channel estimation algorithm is evaluated under various configurations. Results show that the performance of channel estimation is improved as the number of candidate angles and iterations increases.**

***Index Terms*—Channel estimation, direct sequence, spread spectrum, turbo processing, demodulation.**

I. Introduction

The direct sequence spread spectrum (DSSS) is a method for a secure communication system such as military and commercial communications [1]–[3]. In a DSSS system, a transmitted signal is generated by the product of a data symbol and a spreading sequence. At a receiver, the received DSSS signal is despread using the same sequence. It is very difficult to demodulate DSSS signals without information on the spreading sequence.

Several algorithms have been proposed to demodulate the received DSSS signal without information about the spreading sequence [4]–[11]. An ML algorithm is not practical due to its enormous computational complexity [4]. Eigen Value Decomposition (EVD)-based algorithms have been studied since they provide reliable performance within reasonable computational complexity [5]–[10]. However, there is a big performance difference between the ML algorithm and the EVD-based algorithm. To overcome the performance limitation of EVD-based algorithms, a turbo-based algorithm was proposed. A turbo-based algorithm achieves better performance and lower computational complexity than EVD-based algorithms [11]. However, since the turbo-based algorithm in [11] is designed for only an AWGN channel, it is difficult to apply this algorithm to time-varying wireless channels.

To apply a turbo-based algorithm in practical channel environments, a joint channel estimation and spreading sequence detection algorithm is proposed [12]. This algorithm is based on a set of candidate angles designed for channel estimation. With the algorithm, a receiver performs turbo processing to input signals, and a performance metric is computed for each candidate angle. The receiver selects the angle which produces the best performance metric. With this algorithm, channel estimation and sequence detection are performed simultaneously.

In [12], the performance of the proposed algorithm was evaluated for the spreading sequence and data symbol detection. However, the channel estimation performance of the algorithm has not been studied under various configurations. In this paper, the channel estimation performance is evaluated for several configurations.

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II. System model

In this section, a DSSS system model is presented for joint channel estimation and spreading sequence detection.

In the model, Phase Shift Keying (PSK) modulation is used for data transmission. The DSSS signal is generated by the product of the data symbol and the spreading sequence of L binary chips. The one DSSS packet is composed of M data symbols. The DSSS signal is expressed as $s(t)$ is expressed as

$$s(t) = \sqrt{E_s} \sum_{m=1}^{M} d_m \sum_{l=1}^{L} c_l \, p(t - mT_b - lT_c), \qquad (1)$$

where d_m is the m-th data symbol, c_l is the l-th chip of the spreading sequence, E_s is the energy per symbol, and $p(t)$ is a pulse-shaping filter, of which power is normalized as 1. The T_b is the duration of a data symbol and the T_c is the duration of a chip.

At a receiver, the received signal is expressed as

$$r(t) = h(t) * r(t), \qquad (2)$$

where $h(t)$ is a channel response. The channel response $h(t)$ is assumed to be a frequency-flat and slow time-varying fading channel. It is assumed that the channel gain and the phase component are constant during the transmission of one DSSS packet. Therefore, the received signal can be expressed as

$$r(t) = \sqrt{\gamma} e^{j\phi} \cdot s(t) + n(t), \qquad (3)$$

where γ and ϕ are the power and the phase component of the channel response, respectively. Here, $n(t)$ is a zero-mean complex Gaussian noise with variance N_o [13]. Without loss of generality, it is assumed that the power is normalized to

satisfy $\mathbb{E}\{\gamma\} = 1$. The phase component ϕ is uniformly distributed in $[0,\ 2\pi)$. Then, the ratio between the average received E_s and N_o becomes E_s/N_o since $\mathbb{E}\{\gamma\} = 1$.

III. Estimation algorithm

In this section, an algorithm is presented for the joint channel estimation and spreading sequence detection.

It is assumed that the receiver knows chip duration and spreading sequence length. At the receiver, the input matrix for one DSSS packet is expressed as

$$\mathbf{R} = \sqrt{\gamma} e^{j\phi} \cdot \begin{bmatrix} d_1 c_1 & d_1 c_2 & \cdots & d_1 c_L \\ d_2 c_1 & d_2 c_2 & \cdots & d_2 c_L \\ \vdots & \vdots & \ddots & \vdots \\ d_M c_1 & d_M c_2 & \cdots & d_M c_L \end{bmatrix} + \mathbf{N}, \tag{4}$$

where $\mathbf{N}$ is a noise matrix.

With the algorithm, a set of candidate angles is designed for channel estimation [12]. A receiver performs turbo processing to the input matrix for N iterations, and a performance metric is computed for each candidate angle. The receiver selects the candidate angle with the best performance metric, which is the output of the channel estimation. In addition, a receiver outputs the detected sequence and data symbols for the selected candidate angle.

In [12], the two-step algorithm is proposed to enhance the estimation performance under a given complexity constraint. In Step 1, channel response is roughly estimated for a large uncertainty range. In Step 2, a more accurate estimation is performed for the reduced uncertainty range around the result of Step 1. With the two-step algorithm, significant performance improvement can be achieved under similar computational complexity constraints [12].

IV. Result

In this section, simulation results are presented for the joint channel estimation and sequence detection algorithm.

Table 1 shows the simulation parameters used for the results. BPSK modulation is used for data symbols. The spreading sequence is generated from random binary numbers. The number of data symbols M and the spreading sequence length L are set to 50 and 31, respectively.

To enhance the performance, a two-step algorithm is used for the channel estimation. Several configurations are denoted as $(K_1, N_1; K_2, N_2)$, where K_1 is the number of candidate angles N_1 is the number of iterations for Step 1, K_2 is the number of candidate angles and N_2 is the number of iterations for Step 2, respectively. For the results, three different configurations (denoted by config(i), $i = 1, 2, 3$) are considered as shown in Table 1.

TABLE I
Simulation parameters

Modulation scheme	BPSK	
Number of data symbol	50	
Length of spreading sequence	31	
Configurations for Step 1 and Step 2 $(K_1, N_1; K_2, N_2)$	config(1)	(2,2;2,2)
	config(2)	(4,4;4,4)
	config(3)	(8,8;8,8)

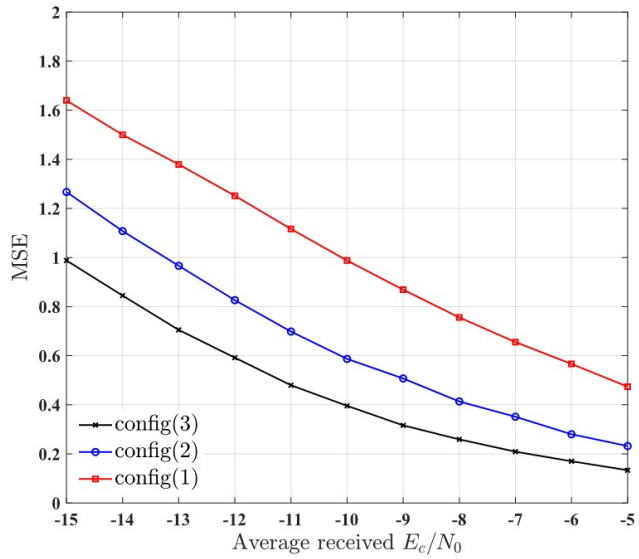

Fig. 1. MSE of estimated phase angle for different configurations.

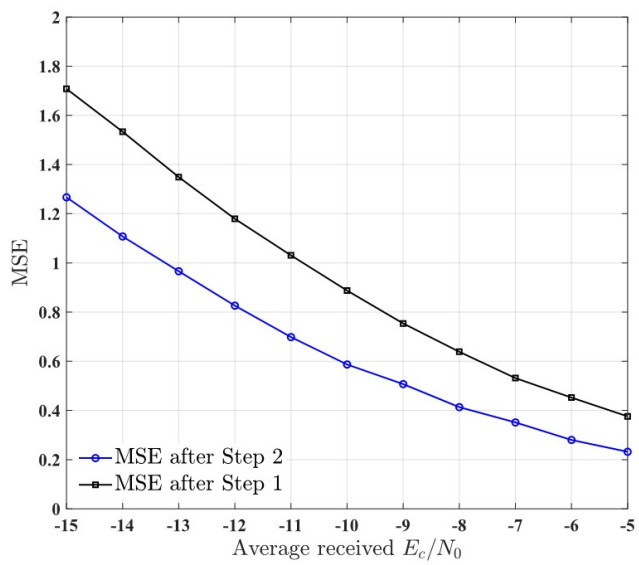

Fig. 2. MSE Comparison after Step 1 and Step 2.

The performance is evaluated for several E_c/N_o values, where $E_c = E_s/L$. The performance measure of the channel estimation is the MSE of the estimated phase angle, which is defined as follows

$$\text{MSE} = \mathbb{E}[\,(\phi - \widehat{\phi})^2\,]. \tag{5}$$

Fig. 1 shows the MSE of the estimated phase angle versus the average received E_c/N_o. For E_c/N_o of -10.0 dB, the MSE is 0.99, 0.59, and 0.40 for config(i), where i is 1, 2, and 3, respectively. From Fig. 2, it can be observed that the MSE

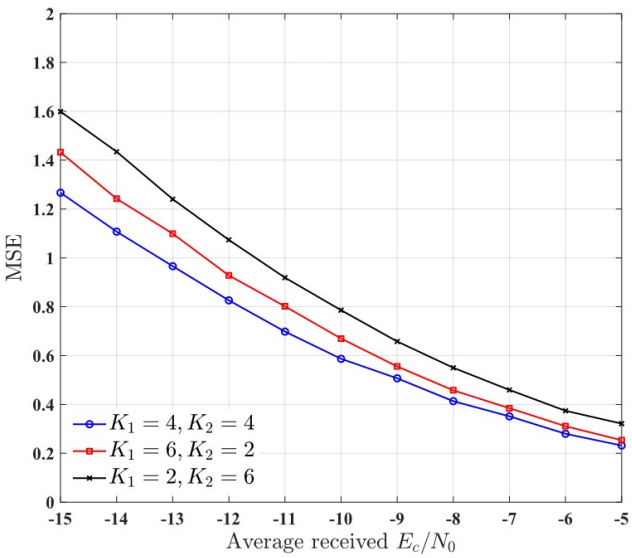

Fig. 3. MSE for different numbers of candidate angles in Step 1 and Step 2.

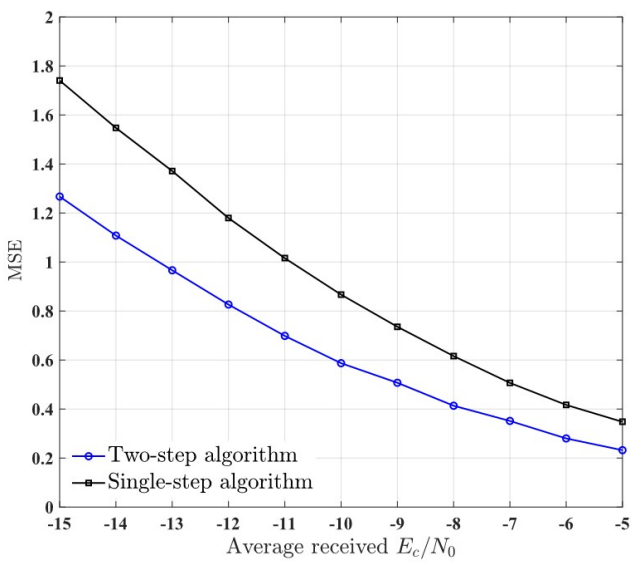

Fig. 4. MSE performances of two-step and single-step algorithms.

decreases as the numbers of candidate angles and iterations increase.

Fig. 2 compares the MSE values of the phase angle after Step 1 and Step 2 versus the average received E_c/N_o. For E_c/N_o of -10.0 dB, the MSE is 0.88 and 0.59 from the estimation results of Step 1 and Step 2, respectively. From Fig. 2, it can be observed that the two-step algorithm enhances channel estimation performance by the fine estimation in Step 2.

Fig. 3 compares the performances of the estimation algorithm for different numbers of candidate angles in Step 1 and Step 2. The computational complexity of the algorithm is proportional to $K_1N_1 + K_2N_2$ [12]. The results are obtained for $N_1 = 4$ and $N_2 = 4$. Fig. 3 shows the MSE performances of the algorithm with similar computational complexity. One is the $K_1 = 4$ and $K_2 = 4$, another is the $K_1 = 6$ and $K_2 = 2$, and the third is $K_1 = 2$ and $K_2 = 6$. Among the three configurations, $K_1 = 4$ and $K_2 = 4$ case shows the best performance.

Fig. 4 compares the MSE performances of two-step and single-step algorithms of similar computational complexity. For a two-step algorithm, config(2) is used. For a sing-step algorithm of similar complexity, the configuration of $K_1 = 8$ and $N_1 = 4$ is used. For E_c/N_o of -10.0 dB, the MSE are 0.59 and 0.87 for the two-step and single-step algorithms, respectively. From the result, it can be observed that the two-step algorithm achieves a lower MSE value than the single-step algorithm.

V. Conclusion

In this paper, the performance of the channel estimation algorithm is evaluated under various parameter configurations. Simulation results show that the performance of channel estimation is improved as the number of candidate angles and iterations increases. A two-step algorithm achieves better channel estimation performance compared to a single-step algorithm.

References

[1] R. L. Peterson, D. E. Borth and R. E. Ziemer, *An introduction to spread-spectrum communications* 1st Ed, Upper Saddle River, NJ, USA: Prentice-Hall, 1995.

[2] A. Viterbi, *CDMA: Principles of Spread Spectrum Communication*. Reading, MA, USA: Addison-Wesley, 1995.

[3] D. Torrieri, *Principles of spread spectrum communication systems*, New Work, NY, USA: Springer, 2005.

[4] S. Mehboodi, A. Jamshidi, and M. Farhang, "Spreading sequence estimation algorithms based on ML detector in DSSS communication systems," *IET Signal Process.*, vol. 12, no. 6, pp. 802-809, Aug. 2018.

[5] M. K. Tsatsanis and G. B. Giannakis, "Blind estimation of direct sequence spread spectrum signals in multipath," *IEEE Trans. Signal Process.*, vol. 45, no. 5, pp. 1241-1252, May 1997.

[6] G. Burel, C. Bouder, and O. Berder, "Detection of direct sequence spread spectrum transmissions without prior knowledge," in *Proc. IEEE Global Telecommun. Conf. (GLOBECOM)*, San Antonio, TX, USA, Nov. 25-29, 2001, pp. 236-239.

[7] T. Zhang, S. Dai, W. Zhang, and G. Ma, "Blind estimation of the PN sequence in lower SNR DS-SS signals with residual carrier," *Digit. Signal Process.*, vol. 22, no. 1, pp. 106-113, Jan. 2012.

[8] Z. Qiu, H. Peng, and T. Li, "A blind despreading and demodulation method for QPSK-DSSS signal with unknown carrier offset based on matrix subspace analysis," *IEEE Access*, vol. 7, pp. 125700-125710, Sep. 2019.

[9] G. Burel, C. Bouder, and O. Berder, "Detection of direct sequence spread spectrum transmissions without prior knowledge," in *Proc. IEEE Global Telecommun. Conf. (GLOBECOM)*, San Antonio, TX, USA, Nov. 25-29, 2001, pp. 236-239

[10] C. Liang, W. Fuping, and W. Zanji, "Low complexity method for spreading sequence estimation of DSSS signal in non-cooperative communication systems," *J. Syst. Eng. Electron.*, vol. 20, no. 1, pp. 41-49, Feb. 2009.

[11] H. Choi and H. Moon, "Blind estimation of spreading sequence and data bits in direct-sequence spread spectrum communication systems," *IEEE Access*, vol. 8, pp. 148066-148074, Aug. 2020.

[12] S. Oh and H. Moon, "Novel algorithm for joint channel estimation and spreading sequence detection in DSSS systems," *IEEE Access*, Sep. 2024. doi: 10.1109/ACCESS.2024.3449284.

[13] B. Sklar, *Digital Communications: Fundamentals and Applications*, Englewood Cliffs, NJ, USA: Prentice Hall, 1988.