ISSN 0735-2727, Radioelectronics and Communications Systems, 2020, Vol. 63, No. 8, pp. 405–417. © Allerton Press, Inc., 2020.
Russian Text © The Author(s), 2020, published in Izvestiya Vysshikh Uchebnykh Zavedenii, Radioelektronika, 2020, Vol. 63, No. 8, pp. 483–496.

Time-Varying Channel Equalization in Underwater Acoustic OFDM Communication System

Anfu Zhu[1*]

[1]*North China University of Water Resources and Electric Power, Zhengzhou, China*
**ORCID: 0000-0003-3412-264X, e-mail: zhuanfu@ncwu.edu.cn*

Received October 17, 2018
Revised June 5, 2020
Accepted June 15, 2020

Abstract—In this paper, three time-varying channel equalization schemes are studied in the underwater acoustic (UWA) Orthogonal Frequency Division Multiplexing (OFDM) communication system. The equalization algorithms are the zero-forcing (ZF) equalization algorithm, and the minimum mean square error equalization (MMSE) algorithm and the serial interference cancellation (SIC) equalization algorithm. Among the schemes, there is a problem of needing a large amount of operation when obtaining the inversion of the channel matrix. Then, to reduce the computation complexity of channel matrix inversion, the band approximation of the channel matrix, the serial equalization and the $\mathbf{LDL}^{H}$ decomposition are also studied. To evaluate the efficacy of the algorithms studied in this paper, numerical simulation and the field experiment are both conducted. The simulation results proof that each equalization algorithm can work appropriately under different time-varying conditions, and valid the reliability of each simplified algorithm under the same Doppler factor. The results of two sets of field experiment also prove that the simplified algorithm eliminates the influence of the residual narrow band Doppler to a certain extent, and a better effect is obtained while a channel estimation algorithm with higher accuracy is combined.

DOI: 10.3103/S0735272720080038

1. INTRODUCTION

With the development of communication technology, the demand for communication through the time-varying underwater acoustic (UWA) channel is gradually increased. Under the condition of the time-varying UWA channel, the Doppler effect generated by the scatterers in the water or the high-speed motion of the transmitter and the receiver will affect the performance of the UWA communication system seriously. In this case, the estimation of the channel matrix of the time-varying UWA channel and the channel equalization technique are necessary to be used to suppress the ICI, especially for the Orthogonal Frequency Division Multiplexing (OFDM) communication system, which is more sensitive to the ICI than the single-carrier communication system.

The channel estimation and equalization algorithms for the time-invariant UWA channel are no longer valid when the channel is time-varying. Therefore, a corresponding system model needs to be established for the time-varying channel, in which time-varying channel estimation and equalization algorithms can be studied. Typically, the equalization techniques should be based on accurate channel estimation.

Many researchers have studied the time-varying channel estimation methods and proposed a variety of channel estimation methods for time-varying channels. Among them, the representative methods are Basis Expansion Model (BEM), and Compressed Sensing (CS) based time-varying channel estimation methods.

The main idea of the BEM is to represent a time-varying channel with Doppler spread as a narrow-band stationary Gaussian process, which can be approximated by superimposing a set of sinusoids with constant amplitude and random phase. M. Tsatsanis first used BEM for time-varying channel modelling and proposed a complex exponential BEM (CE-BEM) [1].

Based on this idea, researchers proposed different BEM models which are based on various basis functions, such as the modified CE-BEM [2], the polynomial BEM (P-BEM) [3], the Discrete Karhunen-Loeve BEM (DKL-BEM) [4], and the Discrete Prolate Spheroidal BEM (DPS-BEM), etc. [5].

The BEM models can represent multiple channels with a small number of base coefficients. In the BEM-based time-varying channel estimation algorithm, the estimation of the time-varying channel can be

CONFLICT OF INTEREST

The author declares that he has no conflict of interest.

ADDITIONAL INFORMATION

The initial version of this paper in Russian is published in the journal "Izvestiya Vysshikh Uchebnykh Zavedenii. Radioelektronika," ISSN 2307-6011 (Online), ISSN 0021-3470 (Print) on the link http://radio.kpi.ua/article/view/S0021347020080038 with DOI: 10.20535/S0021347020080038.

REFERENCES

1. M. K. Tsatsanis and G. B. Giannakis, "Adaptive methods for equalization of rapidly fading channels," in *Proceedings Of MILCOM '93 - IEEE Military Communications Conference* (IEEE, 2002), Vol. 2, pp. 639–643. DOI: 10.1109/MILCOM.1993.408590.
2. I. Barhumi, G. Leus, and M. Moonen, "Estimation and direct equalization of doubly selective channels," *EURASIP J. Adv. Signal Process.* **2006**, No. 1, 062831 (2006). DOI: 10.1155/ASP/2006/62831.
3. S. Tomasin, A. Gorokhov, Haibing Yang, and J.-P. Linnartz, "Iterative interference cancellation and channel estimation for mobile OFDM," *IEEE Trans. Wirel. Commun.* **4**, No. 1, 238 (2005). DOI: 10.1109/TWC.2004.840194.
4. K. A. D. Teo and S. Ohno, "Optimal MMSE finite parameter model for doubly-selective channels," in *GLOBECOM'05. IEEE Global Telecommunications Conference*, *2005* (IEEE, 2005), Vol. 6, pp. 3507. DOI: 10.1109/GLOCOM.2005.1578424.
5. T. Zemen and C. F. Mecklenbrauker, "Time-variant channel estimation using discrete prolate spheroidal sequences," *IEEE Trans. Signal Process.* **53**, No. 9, 3597 (2005). DOI: 10.1109/TSP.2005.853104.
6. G. Taubock and F. Hlawatsch, "A compressed sensing technique for OFDM channel estimation in mobile environments: Exploiting channel sparsity for reducing pilots," in *2008 IEEE International Conference on Acoustics*, *Speech And Signal Processing* (IEEE, 2008), pp. 2885–2888. DOI: 10.1109/ICASSP.2008.4518252.
7. J. Jin, Y. Gu, and S. Mei, "An introduction to compressive sampling and its applications," *J. Electron. Inf. Technol.* **32**, No. 2, 470 (2010). DOI: 10.3724/SP.J.1146.2009.00497.
8. Y. Zhou, Y. Wu, D. Chen, and F. Tong, "Compressed sensing estimation of underwater acoustic MIMO channels based on temporal joint sparse recovery," *Dianzi Yu Xinxi Xuebao/Journal Electron. Inf. Technol.* **38**, No. 8, 1920 (2016). DOI: 10.11999/JEIT151158.
9. H. Huang, W. Su, and X. Jiang, "An improved compressed sensing reconstruction algorithm used in sparse channel estimation," in *2016 IEEE International Conference On Signal Processing*, *Communications And Computing* (*ICSPCC*) (IEEE, 2016), pp. 1–4. DOI: 10.1109/ICSPCC.2016.7753737.
10. L. Jing, C. He, L. Zhang, Q. Meng, J. Huang, and Q. Zhang, "Iterative block decision feedback equalizer with soft detection for underwater acoustic channels," *Dianzi Yu Xinxi Xuebao/Journal Electron. Inf. Technol.* **38**, No. 4, 885 (2016). DOI: 10.11999/JEIT150669.
11. Y. Xie, L. Zhou, and J. Liu, "Linearly time-varying channel estimation method with ICI mitigation for OFDM systems," *Inf. Technol.*, No. 1, 67 (2018). DOI: 10.13274/j.cnki.hdzj.2018.01.016.
12. J. Zhao, K. Huo, Y. Liu, and X. Yang, "Cyclic prefix based phase-coded OFDM radar Doppler offset estimation and compensation," *Dianzi Yu Xinxi Xuebao/Journal Electron. Inf. Technol.* **39**, No. 4, 938 (2017). DOI: 10.11999/JEIT160549.
13. S. Sarowa, H. Singh, S. Agrawal, and B. S. Sohi, "A novel energy-efficient ICI cancellation technique for bandwidth improvements through cyclic prefix reuse in an OFDM system," *Front. Inf. Technol. Electron. Eng.* **18**, No. 11, 1892 (2017). DOI: 10.1631/FITEE.1601333.
14. T. Hrycak and G. Matz, "Low-complexity time-domain ICI equalization for OFDM communications over rapidly varying channels," in *2006 Fortieth Asilomar Conference on Signals*, *Systems And Computers* (IEEE, 2006), pp. 1767–1771. DOI: 10.1109/ACSSC.2006.355065.
15. J. Huang, J. Huang, C. R. Berger, S. Zhou, and P. Willett, "Iterative sparse channel estimation and decoding for underwater MIMO-OFDM," *EURASIP J. Adv. Signal Process.* **2010**, No. 1, 460379 (2010). DOI: 10.1155/2010/460379.
16. L. Rugini, P. Banelli, and G. Leus, "Simple equalization of time-varying channels for OFDM," *IEEE Commun. Lett.* **9**, No. 7, 619 (2005). DOI: 10.1109/LCOMM.2005.1461683.