PILOT AIDED CHANNEL ESTIMATION TECHNIQUE IN TWO DIMENSIONAL SPREADING BASED SYSTEMS

Jiří Blumenstein
Doctoral Degree Programme (2), FEEC BUT
E-mail: xblume00@stud.feec.vutbr.cz

Supervised by: Zbyněk Fedra
E-mail: fedraz@feec.vutbr.cz

Abstract: It has recently been observed that the combination of the OFDM (Orthogonal Frequency Division Multiplex) and the CDMA (Code Division Multiple Access) can achieve notably lower BER (Bit Error Rate) performance in comparison with OFDM itself.

The paper reports on the actual topic of the efficient channel estimation in 2D spreading based systems e.q. VSF-OFCDM (Variable Spreading Factor - Orthogonal Frequency Multiple Acces). The different methods for acquisition of channel state information from pilot carriers are used. The simulations are made for different ETSI channel models.

Keywords: VSF-OFCDM, Two-dimensional spreading, Channel estimation, Channel state information, Pilot subcarriers, ETSI channel model, OFDM, CDMA

1 INTRODUCTION

In 1993 the hybrid techniques combining OFDM and code division multiple access (CDMA) were proposed and as a result there are several variants of combination, for example - OFDM-CDMA, Multi Carrier (MC) CDMA or Direct Sequence (DS) CDMA however the most promising approach seems to be the VSF-OFCDM system proposed by NTT DoCoMo in 2001. [1]

In this paper the channel estimation method based on the pilot subcarriers [2] is proposed for application in VSF-OFCDM. A portion of the subcarriers is selected for pilots, and channel estimation is performed based on the received signals on pilot subcarriers. Moreover throughput is not reduced because the pilot subcarrier replaces only several chip positions and not whole data symbol. Although the pilot subcarriers replaces the chip positions, whole symbol can be properly decoded.

2 TWO DIMENSIONAL SPREADING

Data spreading in VSF-OFCDM system can be done in two dimensions - in the frequency domain and in the time domain. This is the main difference between the OFDM or the CDMA approach. Two dimensional spreading factor (SF) is expressed as:

$$SF = SF_{time} \times SF_{freq}. \tag{1}$$

where the SF_{time} is spreading factor in the time domain and the SF_{freq} is spreading factor in the frequency domain.

Variable spreading means that we can change the spreading factor according actual transmission channel conditions to get lower bit error rate (BER). [3]

3 MODEL OF VSF-OFCDM

This chapter is divided into three sections, firstly the description of the transmitter signal processing is presented, next section deals with channel model and third explains a estimation process:

3.1 THE DESCRIPTION OF THE TRANSMITTER SIGNAL PROCESSING

The following text will describe signal processing in the model of two dimensional spreading system VSF-OFCDM. If $\vec{a}^{x,u}$ is considered as the x-th VSF-OFCDM symbol of the u-th user, then can be written:

$$\vec{a}^{x,u} = \left(a_1^{x,u}, a_2^{x,u}, \ldots, a_k^{x,u}, \ldots, a_{\frac{N}{SF_f}}^{x,u} \right), \tag{2}$$

$$\forall k \in \left[1, \frac{N}{SF_f} \right] : a_k^{x,u} \in \{-1, 1\}$$

where x can be also regarded as the VSF-OFCDM frame number. An element $a_k^{x,u}$ of VSF-OFCDM symbol $\vec{a}^{x,u}$ is a BPSK symbol. It should be noted that the sign $\vec{}$ marks a vector quantity. The N is the number of subcarriers. The spreading of the symbol $\vec{a}^{x,u}$ is done according to:

$$\vec{a}_s^{x,u} = \vec{a}^{x,u} \otimes \vec{\xi}^u \tag{3}$$

wherein $\vec{\xi}^u$ is the spreading sequence (in our case the Hadamard spreading sequences are used) of the u-th user, $u \in [1, U]$ or, it can also be regarded as the number of a row or column of the Hadamard matrix, which has dimensions $SF \times SF$ and each element is from $\{-1, 1\}$. U is the number of code channels. The sign $\otimes$ denotes the Kronecker tensor product.

$$\vec{\xi}^u = (\xi_1^u, \xi_2^u, \ldots, \xi_{SF}^u) \tag{4}$$

After the spreading of the signal, there is a serial into parallel transformation $SP\{.\}\Big|_{N, SF_t \times SF_f}$. The N, SF_t are the numbers of rows and columns respectively. The exact form of the SP transformation is given by the N and SF parameters and can be expressed as:

$$SP\{\vec{a}_s^{x,u}\}\Big|_{N, SF_t \times SF_f} = \tag{5}$$

$$= \begin{pmatrix} a_{s1}^{x,u}\xi_1^u & \cdots & a_{s1}^{x,u}\xi_{SF_t}^u \\ \vdots & \ddots & \vdots \\ a_{s1}^{x,u}\xi_{SF-SF_t+1}^u & \cdots & a_{s1}^{x,u}\xi_{SF}^u \\ a_{s2}^{x,u}\xi_1^u & \cdots & a_{s2}^{x,u}\xi_{SF_t}^u \\ \vdots & \ddots & \vdots \\ a_{s\frac{N}{SF_f}}^{x,u}\xi_{SF-SF_t+1}^u & \cdots & a_{s\frac{N}{SF_f}}^{x,u}\xi_{SF}^u \end{pmatrix},$$

Now we need to insert pilot symbols into the SP matrix. We can write:

$$\psi_{i,j} = \zeta$$

$$\forall i \in \left\{ 1, EG_f + 1, 2(EG_f + 1), \ldots, N \right\}$$

$$\forall j \in \{1, EG_t+1, 2(EG_t+1), \dots, SF_t\} \tag{6}$$

where ψ is a element of the *SP* matrix, ζ is on-receiver-side-known constant, here $\zeta = 1$ is considered and finally i and j are the row and column indexes. The variables EG_t and EG_f are the variables describing the Estimation grid. It means the distances between pilot symbols.

The transformed signal is a input for the IFFT operation, the result $\mathbf{s}_m^{u,x}$ is considered as a VSF-OFCDM frame.

$$\vec{s}_m^{\,u,x} = IFFT\left\{\left\{SP\{\vec{a}_{\mathrm{s}}^{\,x,u}\}_m\Big|_{N,\,SF_t\times SF_f}\right\}^T\right\},\ \forall m \in [1,N] \tag{7}$$

It can be written that:

$$\mathbf{s}^{u,x} = \left[\vec{s}_1^{\,u,x}, \vec{s}_2^{\,u,x}, \dots, \vec{s}_m^{\,u,x}, \dots, \vec{s}_N^{\,u,x}\right] \tag{8}$$

where $\mathbf{s}^{u,x}$ is a matrix with N columns. These columns are the vectors $\vec{s}_m^{\,u,x}$.

$\{.\}^T$ indicates the matrix transposition and where:

$$SP\{\vec{a}_{\mathrm{s}}^{\,x,u}\}_m\Big|_{N,SF_t\times SF_f}$$

is the m-th row of the matrix:

$$SP\{\vec{a}_{\mathrm{s}}^{\,x,u}\}\Big|_{N,SF_t\times SF_f}$$

The duration of one VSF-OFCDM frame is denoted T, i.e. $T = \frac{t_{\mathrm{s}}}{SF_t} = \frac{1}{\Delta F}$, where ΔF is the spacing of the subcarriers.

The transmitted signal is, however, a vector quantity and therefore there is a need to convert the signal $\mathbf{s}^{u,x}$ into $\vec{s}_{\mathrm{PST}}^{\,u,x}$ signal according to:

$$\vec{s}_{\mathrm{PST}}^{\,u,x} = PST\{\mathbf{s}^{u,x}\} = \left(s_{1,1}^{u,x}, s_{2,1}^{u,x}, \dots, s_{SF_t,1}^{u,x}, s_{1,2}^{u,x}, \dots, s_{SF_t,N}^{u,x}\right) \tag{9}$$

The PST abbreviation indicates Parallel Serial transform in the Transmitter.

3.2 Channel model

The transmission channel model is expressed by its impulse response given by ITU which is represented by the sampling of the wide-sense stationary uncorrelated scattering (WSS-US) and by a Doppler shift: [2]

$$h(p,m) = \lim_{R\to\infty} \frac{1}{\sqrt{R}} \sum_{r=1}^{R} e^{(\phi_r + 2\pi f_{D_r} T_s p + 2\pi\tau_r \Delta F m)} \tag{10}$$

3.3 Estimation

The principle of the pilot aided estimation is obvious from the following. Some of transmitted chips in *SP* matrix are putted equal to ζ. This information (ζ) is known at the receiver side and therefore the transmission channel influence at the positions of the pilot symbols can be evaluated.

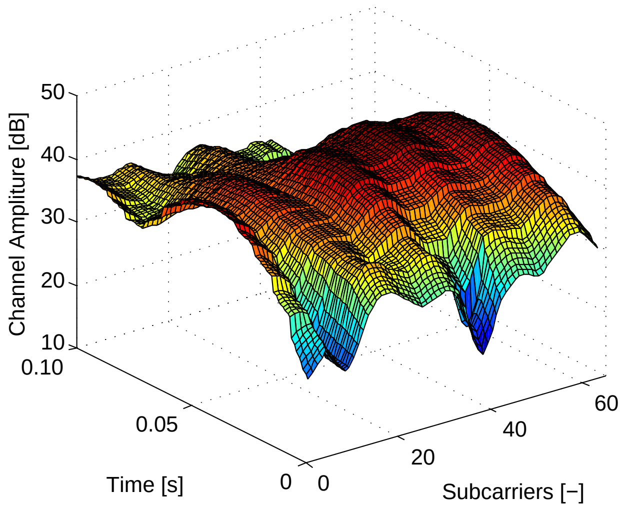

Figure 1: Interpolated CSI matrix, method: Nearest

For applying the CSI there is a need to interpolate this CSI matrix to size of the *SP* matrix. There are used three methods: Linear, Nearest and Spline.

Application of the interpolated CSI matrix is done using a multiplication operation. The interpolated CSI matrix is element-by-element multiplicated with the matrix of the received signal.

4 RESULTS

The BER simulations show (figure 2) that for interpolation of pilot subcarriers to obtain the complete CSI, the Linear and Spline methods have almost same performance. The Nearest has worst performance because the subcarriers near pilot subcarrier have CSI approximated by same value as pilot subcarrier. The CSI for Linear and Spline is approximated by linear regression or with spline interpolation.

By comparing VSF-OFCDM system performance for different channel models (figure 2), the BER is significantly worst in ETU 70Hz. This urban channel has delay spread = 991 ns, that makes data transmission over this channel more challenging.

The simulation shows that even if the pilot subcarriers replaces the chip positions, whole symbol can be properly decoded.

5 CONCLUSION

The paper proposes a novel application of pilot based channel estimation and CSI interpolation in VSF-OFCDM systems. The unaffected throughput is the main advantage of the proposed approach. The performance for different interpolation methods for CSI estimation is shown and simulations are made for three types of non-linear channel models. The nearest method for pilot subcarriers interpolations is not recommended. The linear and spline methods have almost same performance for selected system, but linear is easy to implement. The VSF-OFCDM system with CSI estimation has better performance in channels with smaller delay spread (EPA, EVA) as suspected.

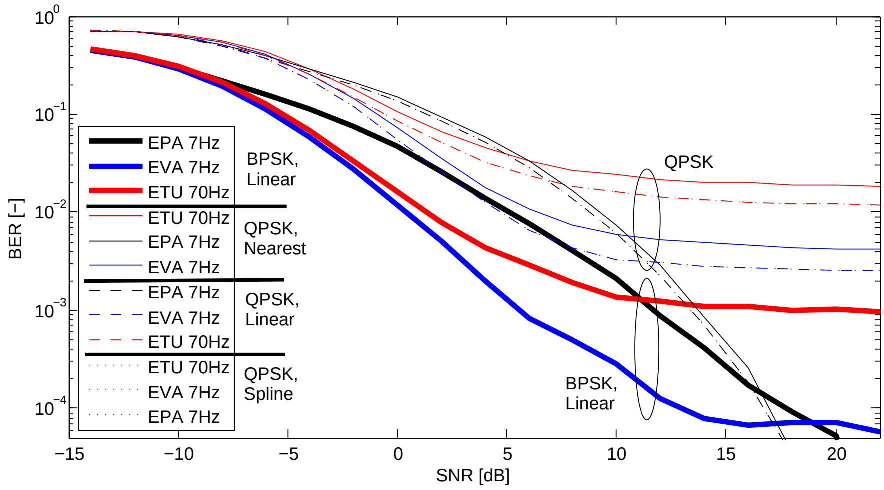

Figure 2: The comparison of BER performance for different interpolations methods for CSI estimation, different channel models and BPSK and QPSK inner modulation VSF-OFCDM

Acknowledgements

This work has been prepared as the part of the solution of the Grant Agency of Czech Republic grants no. P102/10/P513 “Communication systems combining OFDM and CDMA and their PAPR”, and grant no. GD102/08/H027. The research also has also been funded by grant no. FEKT-S-10-6.

REFERENCES

[1] FAZEL, K., KAISER, S. *Multi-Carrier and Spread Spectrum Systems*, 1. publication., John Wiley and Sons Ltd, 2003, 281 p. ISBN 0-420-94899-5

[2] HOEHER P., KAISER S., ROBERTSON P. *Two-Dimensional Pilot-Symbol-Aided Channel Estimation By Wiener Filtering.* In Proceedings of 1997 IEEE Int. Conf. Acoustics, Speech, and Signal Processing, Munich, Germany, Apr. 1997, pp. 1845–1848.

[3] MAEDA, N., KISHIYAMA, Y., ATARASHI, H., SAWAHASHI, M. *Variable spreading factor-OFCDM with two dimensional spreading that priorizes time domain spreading for forward link broadband wireless access.* IEICE Transactions on Communications, 2005, vol.E88-B, no. 2.

[4] SESIA, S., TOUFIK, I., BAKER, M., *LTE The UMTS Long Term Evolution From Theory To Practice*, John Wiley and Sons Ltd., 2009, 611 p. ISBN 978-0-470-69716-0 (H/B)

[5] BLUMENSTEIN, J., FEDRA, Z. *The Characteristics of the 2D Spreading Based Communication Systems.* In Proceedings of 19th International Conference Radioelektronika 2009. 2009. s. 277-279. ISBN: 978-1-4244-3536-4.

[6] HARADA, H., PRASAD, R., *Simulation and software radio for mobile communications.* Artech House, 2002, ISBN 1-58053-044-3

[7] HANZO, L., MÜNSTER, M., CHOI, B.J., KELLER, T., *OFDM and MC-CDMA for Boardband Multi-User Communications, WLANs and Broadcasting*, 1. vyd., John Wiley and Sons Ltd, 2004. 978 s. ISBN 0-470-85879-6

[8] HENG, K., ZENG, G., WANG, W. *Performance analysis for OFDM-CDMA with joint frequency-time spreading.* IEEE Transactions on Broadcasting, 2005, vol. 51, no. 1.

[9] BLUMENSTEIN, J., FEDRA, Z., SEBESTA, V.,*Performance of Pilot Aided Channel Estimation Technique in 2D Spreading Based Systems*, Radioengineering, 2010, roč. 19, č. 4, s. 507-510. ISSN: 1210- 2512.