Performance of Pilot Aided Channel Estimation Technique in 2D Spreading Based Systems

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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

CDMA was developed by the military as a communication system resistant to jamming and monitoring, however CDMA can also be used as a channel access method similarly to the frequency or the time domain multiple accesses. This feature of the channel access is nowadays the main advantage of CDMA used e. g. in the UMTS and in GPS.

OFDM with its orthogonal subcarriers is a popular modulation scheme and has been known since 70's. In fact due to high computational requirements of the Fourier transform, it is used in relatively new standards only (e. g. ADSL, LTE or DVB-T) [1].

In 1993 the hybrid techniques combining OFDM and code division multiple access (CDMA) were proposed [2] and as a result there are several variants of combination, for example - OFDM-CDMA, Multi Carrier (MC) CDMA or Direct Sequence (DS) CDMA [3] however the most promising approach seems to be the VSF-OFCDM system proposed by NTT DoCoMo in 2001 [4].

In this paper a channel estimation method based on the pilot subcarriers [5] is proposed for application in VSF-OFCDM. A portion of the subcarriers is selected for pilots, and channel estimation is performed based on the signals received on pilot subcarriers. Moreover, throughput is not reduced because the pilot subcarrier replaces only several chip positions and not a whole data symbol. Although the pilot subcarriers replace the chip positions, whole symbols can be properly decoded.

Presented simulations shows it applicability for channel estimation in the VSF-OFCDM [6] system, too. The three methods for CSI (Channel State Information) interpolation from pilot subcarrier are tested. Simulations are presented for different channel models (pedestrian, vehicular and urban) [7].

1.1 2D 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 SF_{time} is the spreading factor in the time domain and SF_{freq} is the spreading factor in the frequency domain.

Variable spreading means that we can change the spreading factor according to the actual transmission channel conditions to get lower bit error rate (BER) [6].

In [8] and [9] it was shown that the proper setting of the spreading factor is able to reduce the BER. Moreover, to reduce BER, proper setting of the separate SF_{time} parameter as well as SF_{freq} is of a greater importance than the spreading factor SF. This feature tracks the channel coherence bandwidth and channel coherence time.

A significant drawback of VSF-OFCDM is in high envelope fluctuations of the transmitted signal and thus distortion introduced according to the in fact inevitably nonlinear power amplifier.

2. Model of VSF-OFCDM

This Section is divided into three Subsections. Firstly, the description of the transmitter signal processing is presented, the next part deals with the channel model and the third explains the estimation process.

2.1 The Description of the Transmitter Signal Processing

The following text will describe the signal processing in the model of a 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, it can be written as:

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

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

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 $\vec{\ }$ denotes a vector quantity. N is the number of subcarriers. Spreading of the symbol $\vec{a}^{x,u}$ is done according to:

$$\vec{a}_{\mathrm{s}}^{x,u} = \vec{a}^{x,u} \otimes \vec{\xi}^{u} \tag{3}$$

where $\vec{\xi}^u$ 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 row or column number 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.

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

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:

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

$$= \begin{pmatrix} a_{\mathrm{s}1}^{x,u}\xi_1^u & \cdots & a_{\mathrm{s}1}^{x,u}\xi_{SF_t}^u \\ \vdots & \ddots & \vdots \\ a_{\mathrm{s}1}^{x,u}\xi_{SF-SF_t+1}^u & \cdots & a_{\mathrm{s}1}^{x,u}\xi_{SF}^u \\ a_{\mathrm{s}2}^{x,u}\xi_1^u & \cdots & a_{\mathrm{s}2}^{x,u}\xi_{SF_t}^u \\ \vdots & \ddots & \vdots \\ a_{\mathrm{s}\frac{N}{SF_f}}^{x,u}\xi_{SF-SF_t+1}^u & \cdots & a_{\mathrm{s}\frac{N}{SF_f}}^{x,u}\xi_{SF}^u \end{pmatrix}.$$

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

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

$$\forall i \in \{1, EG_f+1, 2(EG_f+1), \dots, N\},$$

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

where ψ is an 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. They are the distances between pilot symbols. The meaning of Estimation grid is clear from Fig. 1.

The transformed signal is an input to 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

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

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 to as 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 the parallel - serial transform in the Transmitter.

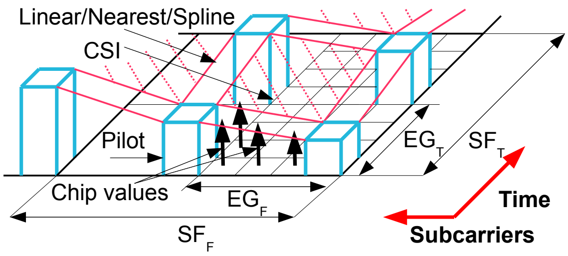

Fig. 1. Pilot insertion.

2.2 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: [5]

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

In this paper the following channel models are used:

- EPA, Extended Pedestrian, r.m.s. delay spread = 43 ns,
- EVA, Extended Vehicular, r.m.s. delay spread = 357 ns,
- ETU, Extended Urban, r.m.s. delay spread = 991 ns,

that simulate the enviroment with low, medium and high (respectively) delay spread and a low (7 Hz for EPA and EVA) and medium (70 Hz for ETU) Doppler shift. The channels have been proposed for use of LTE performance evaluation and therefore the frequencies are around 2.5 GHz. [7]

Spreading Factor SF	64
Spreading Factor - freqv. domain SF_f	8
Spreading Factor - time. domain SF_t	8
Sample time t_s	5 μs
Number od subcarriers N	128
Modulation method	BPSK or QPSK
Upsampling in IFFT	8

Tab. 1. Parameters of the VSF-OFCDM system model.

2.3 Estimation

The principle of the pilot aided estimation is obvious from Fig. 1 and following. Some of transmitted chips in SP matrix are put 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.

For applying the CSI there is a need to interpolate this CSI matrix to the size of the SP matrix. There are three methods used : Linear, Nearest and Spline (see Fig. 1).

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

The difference on perfect knowledge of channel state information (real state of the channel) and channel state information estimated from pilot subcarriers can be seen in Fig. 2 and Fig. 3.

3. Results

The BER simulations show (Fig. 4) that for interpolation of pilot subcarriers to obtaining the complete CSI, the Linear and Spline methods have almost the 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.

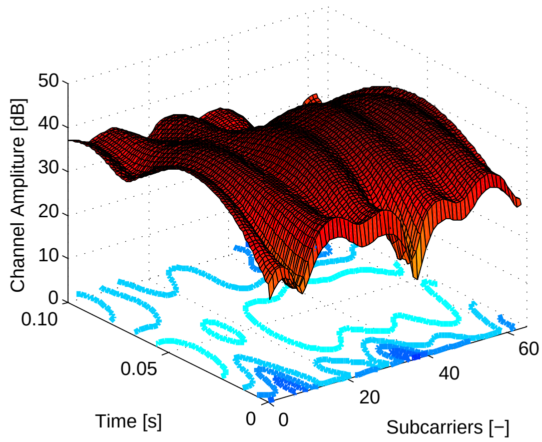

Fig. 2. Real CSI matrix (perfect knowledge of the channel state).

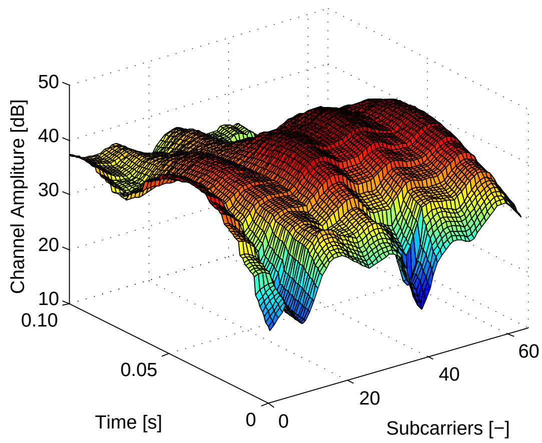

Fig. 3. Interpolated CSI matrix, method: Nearest.

By comparing VSF-OFCDM system performance for different channel models (Fig. 4), the BER is significantly worst in ETU 70 Hz. This urban channel has delay spread = 991 ns, that makes data transmission over this channel more challenging.

The BER performance varies with the different inner modulation of VSF-OFCDM (BPSK or QPSK) too. The BPSK simulation results of CSI estimation method are presented for Linear interpolation only. The QPSK simulations show minimal differences for Linear and Spline interpolation while Nearest interpolations has the worst performance.

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

4. Conclusion

The paper proposes a novel application of pilot based channel estimation and CSI interpolation in VSF-OFCDM systems. Unaffected throughput is the main advantage of the proposed approach. The performance for different inter-

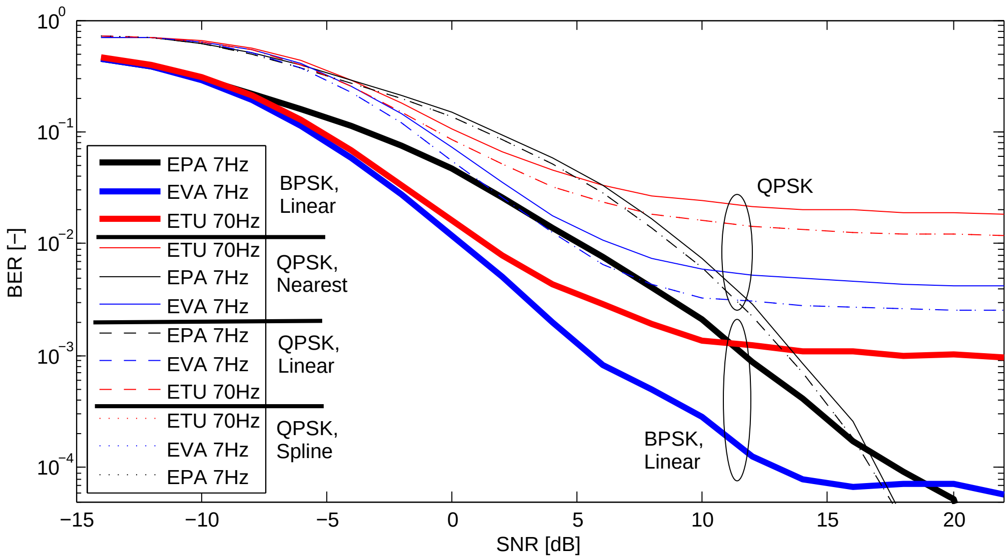

Fig. 4. The comparison of BER performance for different interpolations methods for CSI estimation, different channel models and BPSK and QPSK inner modulation VSF-OFCDM.

polation 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 the same performance for the selected system, but Linear is easier to implement. The VSF-OFCDM system with CSI estimation has better performance in channels with smaller delay spread (EPA, EVA) as expected.

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