Improving OFDM/DQPSK System Performance in the Conditions of Frequency Offset Existence

Zorica B. Nikolić, Bojan R. Dimitrijević, Nenad D. Milošević and Slavimir N. Stošović

Abstract — **The basic characteristics of Orthogonal Frequency Division Multiplex (OFDM) systems with DQPSK modulation and channel estimation with an adaptive transversal filter and LMS algorithm are analyzed and presented in this paper. In the simulation environment designed for this purpose, we analyzed the effects of frequency offset on the performance of OFDM digital communications and presented the method for improving system performance in the presence of frequency offset. We analyzed the influence of OFDM system parameters on system's performance for various values of frequency offsets, filter lengths and the number of subcarriers. Finally, we compared the result with the one for a perfectly synchronized OFDM/DQPSK system with differential and coherent demodulation.**

Keywords — orthogonal frequency-division multiplexing, differential quadrature phase-shift keying, frequency offset, frequency synchronization, LMS algorithm, adaptive transversal filter.

I. Introduction

ORTHOGONAL Frequency Division Multiplexing (OFDM) is a special kind of multicarrier modulation, where a block of data symbols is simultaneously transmitted on a group of subcarriers with frequency-division multiplexing. Within one OFDM symbol duration, each subcarrier is modulated with a data symbol using any conventional method, such as quadrature amplitude modulation (QAM), M-ary phase-shift keying (MPSK), M-ary differential phase-shift keying (MDPSK), as in a single-carrier system. The spacing between adjacent subcarriers is carefully selected so that each subcarrier is located on all the others' spectral nulls, and all the subcarriers are also packed as closely as possible. Because of this spectral orthogonality, the modulation symbols on all the subcarriers can be ideally recovered by sampling the received baseband signal at a rate which is the reciprocal of the intercarrier spacing followed by a fast Fourier transform (FFT).

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In the OFDM system, the intersymbol interference problem caused by delay spread of dispersive fading channels can be overcome by inserting a guard interval between adjacent OFDM symbols. The Doppler spread due to the motion of a terminal destroys orthogonality of OFDM signal and introduces interchannel interference (ICI) on the demodulated OFDM signal. ICI degrades the system performance and results in an irreducible error rate. In frequency-nonselective fading channels, equalization combined with channel estimation has been proposed to combat the ICI problem. In frequency-selective fading channels, a channel estimation technique is used to compensate for multiplicative distortions on the demodulated OFDM signals. At slow fading, DPSK modulation in the temporal direction has a good performance as phases of multiplicative distortions are assumed to be constant during consecutive OFDM symbol intervals.

The popularity of OFDM systems is rising due to their ability to support high-data-rate transmission over time-variant multipath fading channels. OFDM is used in the standards for wireless local area networks [1], [2]. Asymmetric digital subscriber lines (ADSL) based on OFDM technology are used to deliver high-rate digital data over existing plain old telephone lines [3]. OFDM can also serve as an alternative transmission method to DECT-like digital cordless systems [4].

Numerous methods for estimation and correction of frequency offset are proposed. Some of them use redundancy inherently built in every OFDM symbol, because of cyclic prefix usage, [5, [6]. The second group of estimation methods is based on the use of special pilot sequences for frequency offset estimation [7], [8].

In this paper, we present the performance of OFDM system with DQPSK modulation in an AWGN (Adaptive white Gaussian noise) channel. For this purpose we designed a special simulation platform and analyzed the influence of OFDM system parameters on system performance for various values of the filter length (L) and number of OFDM subchannels (N). The performance of OFDM/DQPSK system in the presence of frequency offset is also shown. Using channel estimation and correction with ATF and LMS algorithm the improvement of OFDM system performances achieved.

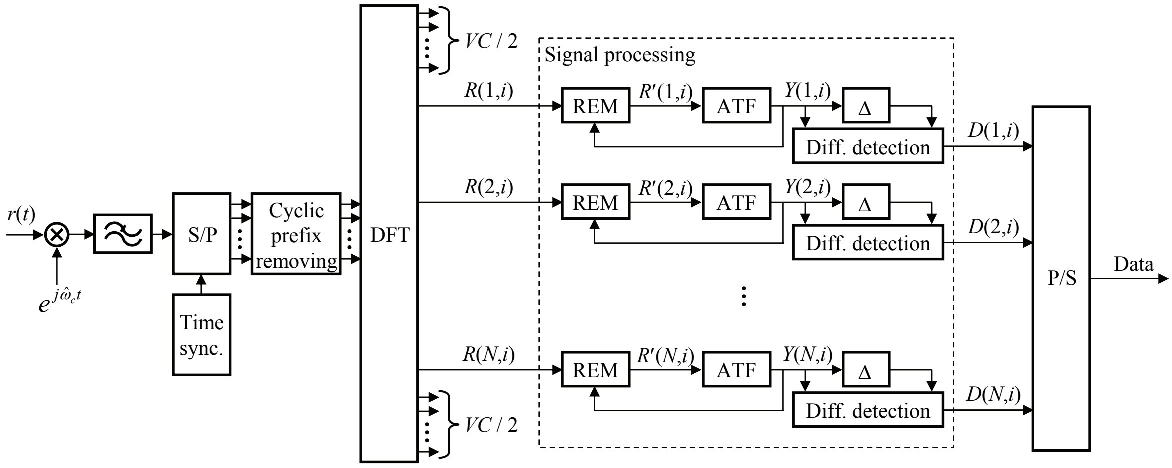

Fig 1. Model of the proposed OFDM receiver.

II. System Model

The OFDM signal, at the output of the transmitter may be written as:

$$s(t) = \frac{1}{N}\mathrm{Re}\left\{\sum_{i=-\infty}^{\infty}\sum_{n=0}^{N} d_{n,i}\, g(t-iT_s)e^{j2\pi(f_c+f_n)t}\right\}, \quad (1)$$

where $d_{n,i}$ is a complex data symbol, $g(t)$ is the impulse response of transmitter filters, f_c is the carrier frequency, $f_n = n/T_s, n = 0,...,N$ is the n-th subcarrier frequency, and $1 / T_s$ is the symbol rate associated with each subcarrier.

Block diagram of the proposed OFDM receiver is shown in Fig. 1. A received signal is down converted, low-pass filtered, and sampled with the period

$$T = \frac{T_s}{N+CP+GI} \quad (2)$$

where GI is the guard interval duration, and CP is the cyclic prefix duration, both expressed in the number of sampling periods, i.e. $T_{GI} = GI \cdot T$, $T_{CP} = CP \cdot T$. A locally generated carrier has frequency $\hat{f}_c = f_c + \Delta f$, where Δf is the frequency offset between the received signal and the locally generated carrier frequency.

Block S/P represents a serial to parallel converter and it requires timing synchronization. After removing the cyclic prefix, a discrete Fourier transform (DFT) of length N is performed. DFT received and reconstructed OFDM data frame at the input, and transmitted modulated symbols influenced by frequency channel response are at the output. In this case we use OFDM demodulator with N subcarriers and discrete Fourier transform. Input is in time, and output in the frequency domain.

Signal processing is realized with the proposed model shown in Fig. 1. Block labelled with ATF reperesents an adaptive transversal filter that uses LMS algorithm for weights adjustment. This block is described with the following set of equations:

$$Y(k,i) = \frac{1}{L}\sum_{j=1}^{L} R'(k,i-j)W_j(k,i) \quad (1)$$

where L is the filter length, and $Y(k,i)$ represents a complex baseband signal at the output of adaptive filter in the k-th channel and i-th discrete time instant. Filter weights are adjusted by LMS algorithm:

$$W_j(k,i+1) = W_j(k,i) + \frac{\mu E(k,i)(R'(k,i))^*}{\left|R(k,i)\right|^2} \quad (2)$$

Where

$$E(k,i) = R'(k,0) - Y(k,i) \quad (3)$$

$$R'(k,i) = R(k,i)W_s \quad (4)$$

and $W_s \in \{1, j, -1, -j\}$; $R(k,i)$ is the kth output of DFT block at the ith time instant, and μ is the LMS algorithm convergency factor.

Parameter W_s is calculated as

$$W_s \Leftarrow \min_{W_s}\left\{\left|Y(k,i) - R(k,i)W_s\right|^2\right\} \quad (5)$$

Detection of the i-th symbol is performed as

$$D(k,i) \Leftarrow \min_{D(k,i)}\left\{\left|Y(k,i) - Y(k,i-1)D(k,i)\right|^2\right\} \quad (6)$$

III. Numerical Results

The performance of the proposed system is analyzed using Monte-Carlo simulation. The carrier frequency is 5 GHz. For each channel we used channel estimation and correction with ATF and LMS algorithm and tested OFDM system performances as a function of parameter L. Three different cases were simulated. In the first case, the number of subcarriers is $N = 16$, the number of virtual channels is $VC = 2$, cyclic prefix duration is $CP = 2$, and guard interval duration is $GI = 2$. In the second case, the following parameters are used: $N = 32$, $VC = 4$, $CP = 4$, and $GI = 4$. Finally, in the third case, parameters are: $N = 64$, $VC = 8$, $CP = 4$, and $GI = 8$.

Figs. 2, 3 and 4 show OFDM system bit error rate (BER) as a function of the energy per bit to noise power spectral density ratio (E_b / N_0), for different values of filter length L, in the presence of frequency offset, Δf=75 kHz (dashed lines) and without frequency offset (solid lines).

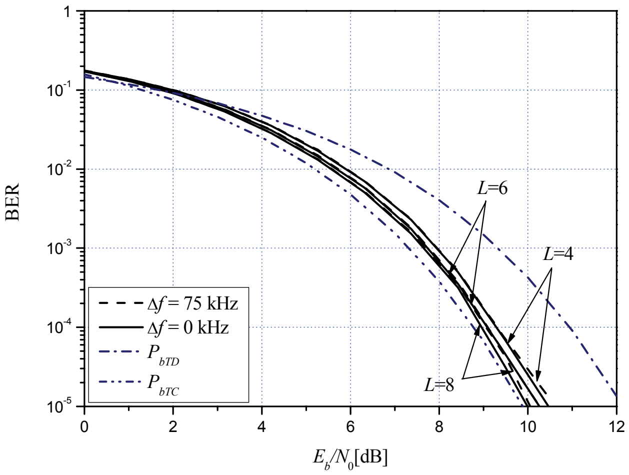

Fig. 2. Bit error rate versus E_b/N_0 for N=16 and VC=GI=CP=2.

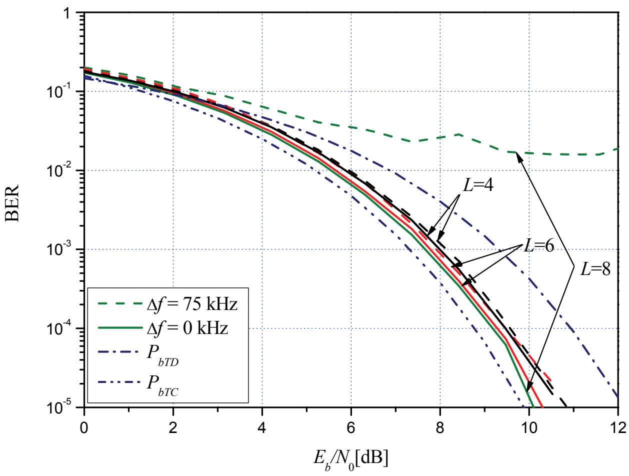

Fig. 3. Bit error rate versus E_b/N_0 for N=32 and VC=GI=CP=4.

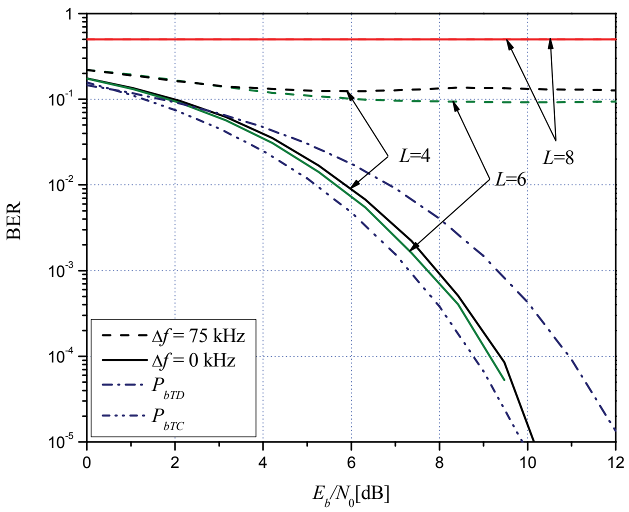

Fig. 4. Bit error rate versus E_b/N_0 for N=64 and VC=GI=CP=8.

Fig. 2 shows OFDM system performances, in the first case (N=16, VC=GI=CP=2), versus E_b / N_0. It can be seen that system performances do not depend much on parameter L. Also, bit error rate difference in the presence of the frequency offset compared to the bit error rate without frequency offset is very small.

For comparison, there are two theoretical curves for bit error probability in an AWGN channel, with perfect synchronization, given as [9]

$$P_{bTD} \approx Q\sqrt{\frac{4E_b}{N_0}}\sin\frac{4\pi}{\sqrt{2}}, \tag{7}$$

and

$$P_{bTC} \approx 2Q\sqrt{\frac{2E_b}{N_0}}, \tag{8}$$

for differentially demodulated DQPSK signal (P_{bTD}), and coherently demodulated DQPSK signal (P_{bTC}). Function $Q(x)$ is also defined in [11].

We can see that the proposed system's performances are better than the ones of differentially demodulated, and very close to the coherently demodulated DQPSK signal. So, with the receiver that does not need coherence we achieved results very close to the coherent receiver.

Similarly, Figs. 3 and 4 show the performance of system in the second and the third case versus E_b / N_0 with L as a parameter, respectively. It can be seen that the frequency offset causes a performance drop compared to the ideally synchronized system, and the performance drop rises with the increase of filter length and the number of subcarriers.

Figs. 5, 6, and 7 show bit error rate versus frequency offset Δf, with filter length L as a parameter, and $E_b/N_0 = 8$ dB. For smaller values of parameter L, frequency offset has a smaller influence on the system performance. It means that, the band within which it is possible to achieve satisfying transmission quality is the widest. With the increase of parameter L, the influence of frequency offset on transmission quality also increases. Frequency offsets range where there is a satisfying transmission quality becomes narrower, but *BER* is better. Fig. 5. also shows simulation results for the DQPSK signal differential detection without frequency offset estimation and correction (curve DD_{DQPSK}). We can conclude that the proposed OFDM receiver has a better error probability, but the range where there is a satisfying transmission quality is narrower, compared to the receiver that uses differential detection without frequency offset estimation and correction.

It can also be seen that the frequency offsets range, where there is a satisfying transmission quality, becomes narrower with the increase of the number of subcarriers and the filter length.

Also, the proposed receiver has a better performance than the receiver with differential detection if the number of subcarriers is equal to 16 and 32, and for a small filter length L = 4. The previous conclusion holds for frequency offsets range of ± 100 kHz.

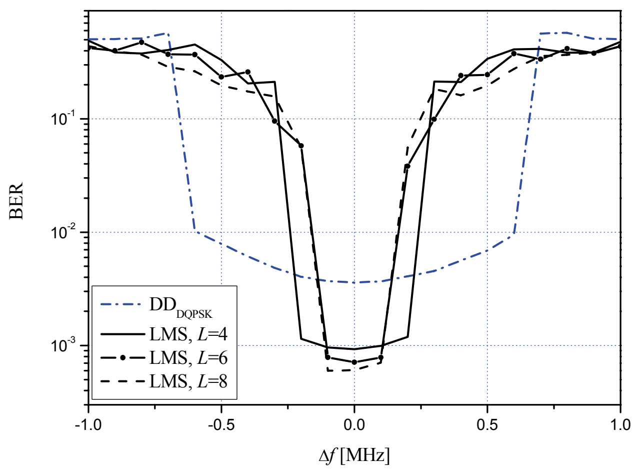

Fig. 5. Symbol error rate versus frequency offset Δf for N=16 and VC=GI=CP=2.

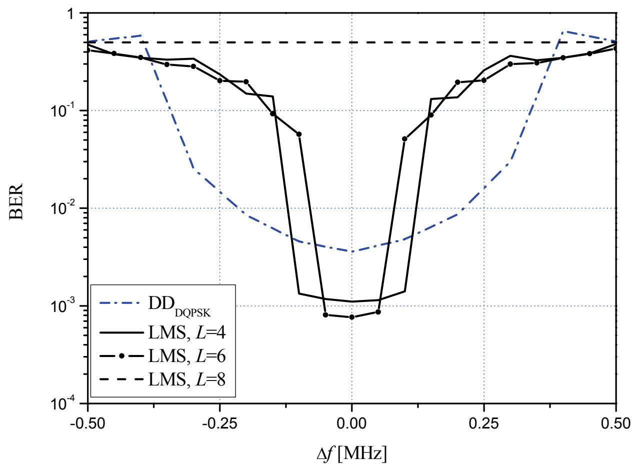

Fig. 6. Symbol error rate versus frequency offset Δf for N=32 and VC=GI=CP=4.

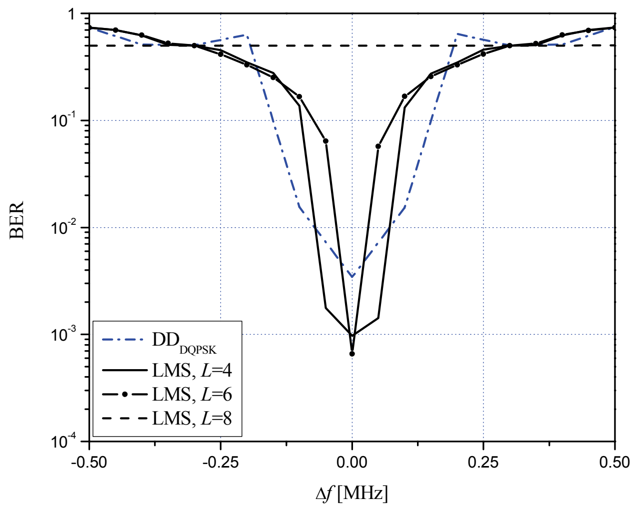

Fig. 7. Bit error rate versus frequency offset Δf for N=64 and VC=GI=CP=8.

IV. Conclusion

In this paper we proposed a new OFDM/DQPSK receiver where signal detection is based on the use of adaptive transversal filter with LMS algorithm. It was shown that in case of small frequency offsets the proposed receiver has performances very close to the theoretical ones for the coherent DQPSK receiver, and the advantage of the proposed receiver is that it does not require carrier frequency estimation. Also, the proposed OFDM receiver has better error probability, but the range where there is a satisfying transmission quality is narrower, compared to the receiver that uses differential detection without frequency offset estimation and correction.

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