Influence of Frequency Offset on the Reception of OFDM/QPSK Signal using MBDD Algorithm

Bojan Dimitrijević, Slavimir Stošović, Nenad Milošević, and Zorica Nikolić

Abstract — **In this paper we present the basic characteristics of Orthogonal Frequency Division Multiplex (OFDM) systems with quadrature phase shift keying (QPSK) modulation and multi-bit differential detection (MBDD). In the simulation environment designed for this purpose, we analyze the effects of frequency offset on the performances of OFDM digital communications. We also analyze the influence of OFDM system parameters on system performances for various values of frequency offset, number of bits for multi-bit detection and the number of subcarriers. We have shown the advantages and disadvantages of using MBDD in the OFDM systems.**

Keywords — **orthogonal frequency division multiplexing, differential quadrature phase shift keying, multi-bit differential detection, frequency offset, frequency synchronization.**

I. Introduction

Orthogonal frequency-division multiplexing has gained a great deal of attention lately and is considered as a strong candidate for many next-generation wireless communication systems. OFDM transmission techniques have found applications in the two digital terrestrial broadcasting services - digital audio broadcasting (DAB) and digital terrestrial video broadcasting (DTVB) [1], [2]. OFDM is used in the standards for wireless 5-GHz local area networks (IEEE 802.11a and HIPERLAN) [3], [4]. Asymmetric digital subscriber lines (ADSL) based on OFDM technology are used to deliver high-rate digital data over existing plain old telephone lines (POTS) [5]. More recent developments such as IEEE802.16 wireless metropolitan area network (WMAN) [6] standard address broadband fixed wireless access (BFWA) uses OFDM. OFDM is also being considered in the IEEE802.11n standard that considers Multiple-Input Multiple-Output (MIMO) systems.

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OFDM waveforms are resilient to timing errors, yet highly sensitive to frequency offsets and phase noise in the transmitter and receiver RF and sampling clock oscillators. 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, [7], [8]. The second group of estimation methods is based on the use of special pilot sequences for frequency offset estimation [9], [10].

In this paper, we present the performance of OFDM system, with quadrature phase shift keying (QPSK) modulation and multi-bit differential detection (MBDD) at the receiver, in an AWGN (Adaptive white Gaussian noise) channel. There are various algorithms for MBDD, such as algorithms shown in [11], [12]. MBDD, for larger number of bits in detection, is more sensitive to frequency offset than conventional DQPSK, but MBDD has a better bit error rate (BER), as shown in [13]. Therefore, it is expected that the OFDM system with QPSK modulation and MBDD is more sensitive to frequency offset than OFDM system with QPSK modulation and conventional differential detection. For this purpose we have designed a special simulation platform and analyzed the influence of OFDM system parameters on system performance for various values of the number of OFDM subchannels (N), and the number of bits (N_B) in multi-bit differential detection. A special case, when the $N_B = 2$ corresponds to conventional differential detection. Characteristics of OFDM/DQPSK system are shown in [14].

II. System Model

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

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

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

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

$$T = \frac{T_s}{N + CP + GI} \tag{2}$$

where GI is the guard interval duration, and CP is the cyclic prefix duration, both expressed in the number of

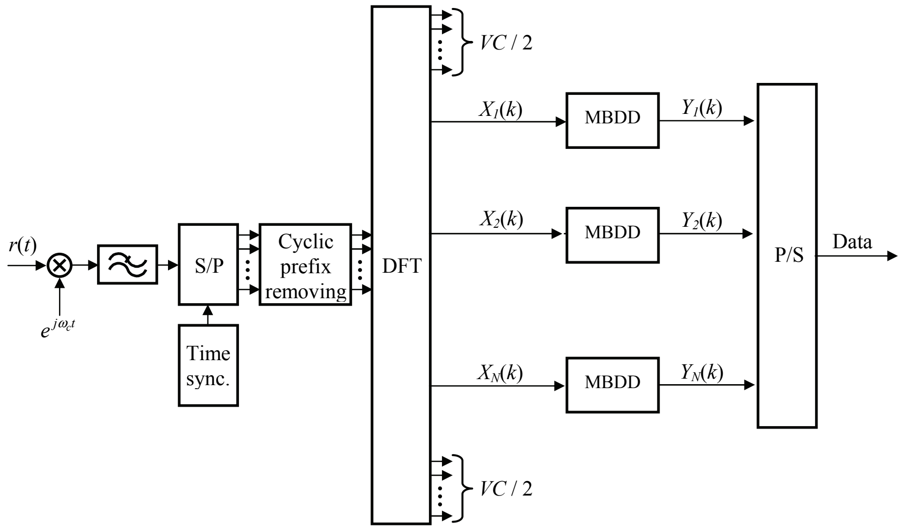

Fig. 1. Proposed model of OFDM/QPSK receiver with MBDD.

sampling periods, i.e. $T_{GI} = GI \cdot T$, $T_{CP} = CP \cdot T$. *VC* is the virtual channels duration.

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 receives and reconstructs an OFDM data frame at the input. Transmitted modulated symbols influenced by frequency channel response are at the output. In this case we use an OFDM demodulator with *N* subcarriers and a discrete Fourier transform. Input is in time and output in the frequency domain. Within one OFDM symbol duration, each subcarrier data symbol is passed through a MBDD demodulator.

After DFT, a block for multi-bit differential decoding (MBDD in Fig. 1, as shown in [12]), firstly makes a hypothesis for the value of N_B bits, since each bit can only acquire values from the following set $\{1, j, -1, -j,\}$, because we apply QPSK modulation. Each hypothesis corresponds to different combinations of bits values from the previous set. The number of hypotheses is calculated based on [13] and for the QPSK system shown with the following equation:

$$N_H = 4^{N_B-1} \tag{3}$$

The estimated bit in *c*-th OFDM channel, $\hat{d}_c(k)$ is determined in the signal processing block by the proposed algorithm that will be described in the following text. In each OFDM channel and for each hypothesis we calculate the corresponding sum. The sum for the *i*-th hypothesis and *c*-th OFDM channel is:

$$R_{c,i}(k) = \mathrm{Re}\left\{ \sum_{m=0}^{N_B-2} \sum_{n=m+1}^{N_B-1} X_c(k-m) X_c^*(k-n) \times \right.$$

‘ $$\left. \times \exp\left(-j \sum_{l=m}^{n-1} \theta_j(k,l) \right) \right\} \tag{4}$$

$$i = 0,1,\ldots,N_H - 1$$

where $X_c(k)$ is c-th output of DFT block at *k*-th time instant, *i* denotes the number of hypotheses, which ranges from 0 to *NH-1*, $Y_c(k)$ represents complex baseband signals at *k*-th time instant for *c*-th OFDM channel, at the outputs of corresponding blocks and:

$$Y_c(k) = \hat{d}_c(k) \tag{5}$$

$$\theta_i(k,l) = \left(\frac{i}{4^l} \bmod 4 \right) \frac{\pi}{2} \tag{6}$$

Now, we first find the maximum value of $R_{i,j}(k)$ with respect to *i*

$$R_{c\max}(k) = \max_i R_{c,i}(k) \tag{7}$$

The value of *i* that determines the maximum value of $R_{c,i}$ (R_{cmax}) is denoted as $i_{max}(k)$:

$$i_{\max}(k) = \arg\max_i R_{c,i}(k) \tag{8}$$

The detected symbol is equal to

$$\hat{d}_c(k) = \frac{i_{\max}(k)}{4^{\frac{N_B-1}{2}}} \bmod 4 \tag{9}$$

P/S represents a parallel to serial converter and at the output, we have a received datastream.

III. Numerical Results

The performance of the described system is analyzed using Monte-Carlo simulation. Simulation parameters are chosen in accordance with the set of IEEE 802.11 standards, which does not diminish the generality of results. The carrier frequency is 2.4 GHz, and the duration of each channel is T_s=10 ns. For each channel we used QPSK modulation and multi-bit differential detection at the receiver. We tested OFDM system performances as a function of parameters *N* and N_B, without frequency offset estimation and correction. 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 $GI = 2$, expressed in the number of T_s. 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: $N = 64$, $VC = 8$, $CP = 8$, and $GI = 8$.

Fig. 2. shows OFDM system bit error rate as a function of the energy per bit to noise power spectral density ratio (E_b / N_0), for different values of multi-bit level N_B, in the presence of frequency offset, $\Delta f = 200$ kHz (dashed lines) and without frequency offset (solid lines) for the first simulated case, when $N = 16$. If the system is ideally synchronized ($\Delta f = 0$ kHz) the curves for all values of parameter N_B have similar characteristics, but the performance is the best when N_B is the largest. It can be seen that system performances depend much on parameter N_B. As we increase N_B, performance improvement is less significant. For example, difference between the curves for $N_B = 2$ and $N_B = 3$ is much greater than the difference between the curves for $N_B = 4$ and $N_B = 5$. That leads to the fact that increasing of N_B, leads to an increase in the complexity of the system, but it does not improve system performances significantly.

In the presence of frequency offset the best performances are for $N_B = 2$ and with increasing of parameter N_B performances are much worse. System is much sensitive to frequency offset for larger values of parameter N_B. Also, one can see that in the presence of frequency offset, maximum deviation from the ideally synchronized system ($\Delta f = 0$ kHz) is in case when the value of N_B is the largest ($N_B = 5$).

Fig. 3 shows bit error rate versus frequency offset Δf, with N_B as a parameter, with $E_b/N_0 = 8$ dB and $N = 16$. For smaller values of parameter N_B, frequency offset has less 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 N_B, the influence of frequency offset on transmission quality also increases. Frequency offsets range where there is a satisfying transmission quality becomes narrower. Frequency offset range is wider for smaller values of parameter N_B, but in this case BER is higher around $\Delta f = 0$ Hz. OFDM/QPSK system with multi-bit differential detection at the receiver is less sensitive to frequency offset for the smaller values of parameter N_B, but the system has a better BER for larger values of parameter N_B.

Figs. 4 and 5, show bit error rate versus frequency offset Δf, with N_B as a parameter, $N = 32$ and $N = 64$, respectively. The curves have the same behaviour as the curves from Fig. 3.

From Figs. 3, 4 and 5 we can also conclude that the band within which it is possible to achieve satisfying transmission quality depends of the number of subchannels (N), and it is the widest when N has smaller values (N=16). With the increase of parameter N, the influence of frequency offset on transmission quality also increases. Frequency offsets range where there is a satisfying transmission quality becomes narrower.

IV. CONCLUSION

Comparing OFDM systems with QPSK modulation and multi-bit differential detection at the receiver in the presence of frequency offset for different numbers of sub-

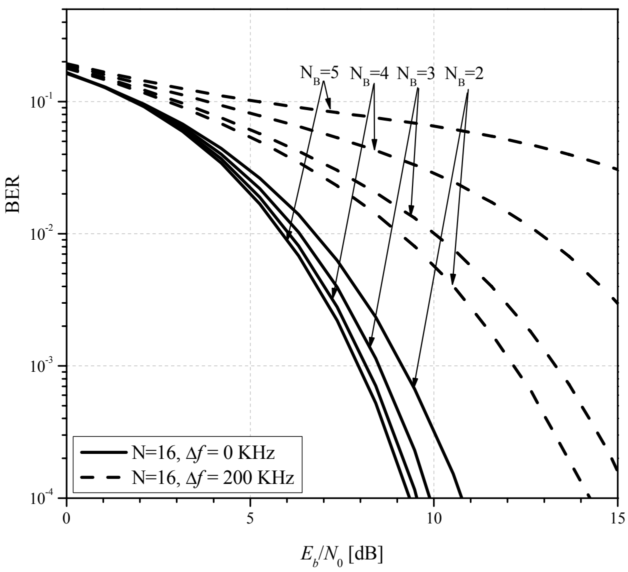

Fig. 2. Bit error rate versus E_b/N_0 for OFDM/QPSK system with MBDD.

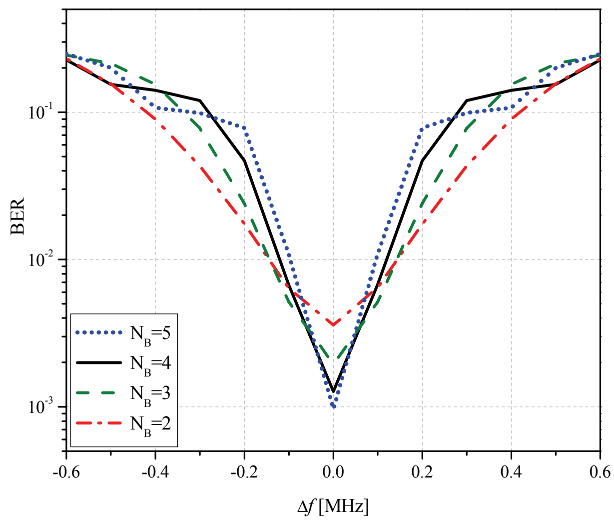

Fig. 3. Bit error rate versus frequency offset Δf for OFDM/QPSK system with MBDD (N=16).

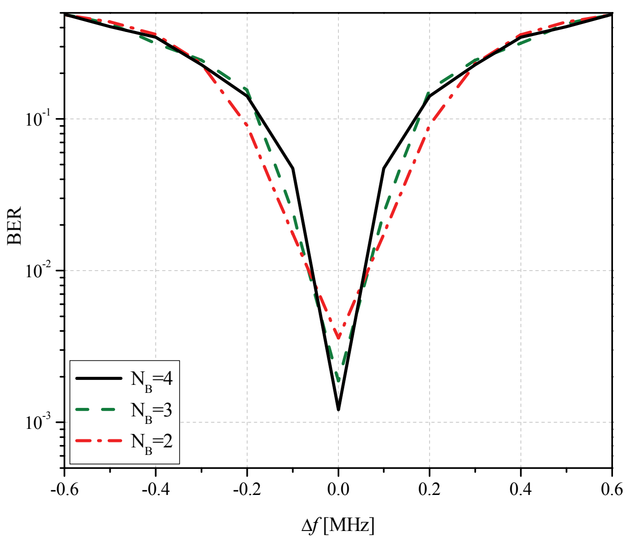

Fig. 4. Bit error rate versus frequency offset Δf for OFDM/QPSK system with MBDD (N=32).

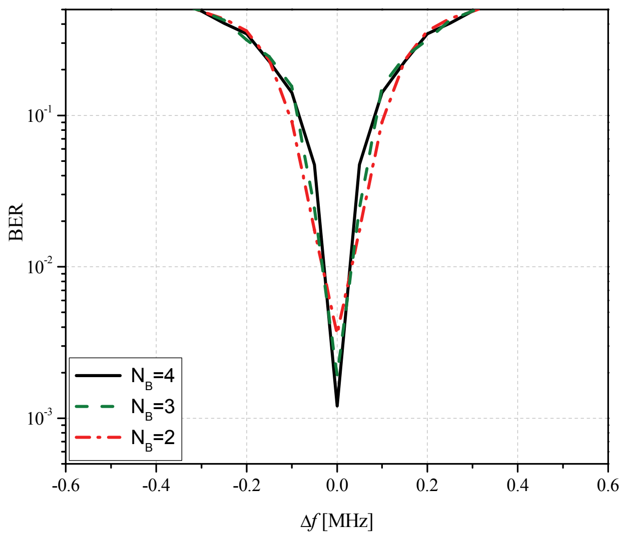

Fig. 5. Bit error rate versus frequency offset Δf for OFDM/QPSK system with MBDD (N=64).

chanels and number of bits in multi-bit detection, one can conclude that the described system is less sensitive to frequency offset for smaller values of the number of bits that are compared during the detection (N_B), but the system has a better BER for larger values of parameter N_B.

For different values of the number of OFDM channels, curves showing BER versus frequency offset have the same characteristics, but the range where there is a satisfying transmission quality is wider for smaller parameter N. This is expected because increasing the number of channels reduces the bandwidth. Therefore, the observed frequency offset makes the percentage of different widths for different value of the OFDM channels.

It means that sensitivity to frequency offset of OFDM system with QPSK modulation and multi-bit differential detection increases when we increase N_B. Also with the increase of N_B, bit error rate gets better around $\Delta f = 0$ Hz, but the complexity of the system also increases, and system performances are not improved significantly. Finally, satisfying transmission quality can be achieved in a narrow frequency band.

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