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OFDM/DPSK System Performance Improvement in the Presence of Frequency Offset using a Reconfigurable Detection Algorithm

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Introduction

The popularity of OFDM systems is rising due to its ability to support high-data-rate transmission over time-variant multipath fading channels. 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 local area networks [3]. Asymmetric digital subscriber lines (ADSL) based on OFDM technology are used to deliver high-rate digital data over existing plain old telephone lines [4]. OFDM can also serve as an alternative transmission method to DECT-like digital cordless systems [5].

One of the challenging problems faced in the design of OFDM systems is the frequency offset between the local oscillators at the transmitter and the receiver [6, 7]. The frequency offset destroys the orthogonality of the OFDM subcarriers, arising from discrete orthogonal transforms [8], and therefore creates Inter-Carrier Interference (ICI). The sensitivity of OFDM to the frequency offset is the major factor limiting the use of OFDM at smaller carrier spacing. To mitigate this effect two types of solutions have been proposed in the literature: Frequency Offset Estimation and Self-Cancellation [9].

Modern software and cognitive radio system are often based on adaptive [10] and reconfigurable structures. Reconfigurable structures may for many purposes at mentioned systems, such as for interference rejection [11].

In this paper we modify the ordinary differential detection and make it reconfigurable, so that it can be used for the DPSK signal reception in the presence of significant frequency offsets. The proposed OFDM receiver (RDD-OFDM) has better performance than the ordinary OFDM receiver with differential detection (DD-OFDM) for any considered frequency offset. The analysis will show that the bit error probability of the proposed reconfigurable algorithm in OFDM system is nearly constant in a wide frequency offsets range of practical importance. The proposed algorithm may be used in mobile communication systems in the presence of large Doppler due to relative movement between the mobile unit and base station.

System model

Block diagram of the proposed OFDM receiver is shown in Fig. 1. 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 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, and $1/T_s$ is the symbol rate associated with each subcarrier.

Signal at the input of the receiver is

$$r(t)=s(t)+n(t), \quad (2)$$

where $s(t)$ is the useful DPSK signal and $n(t)$ is white Gaussian noise with power spectrum density $N_0/2$. Received signal is down converted, low-pass filtered, and sampled with the period

$$T=\frac{T_s}{N+CP+GI}, \quad (3)$$

where GI is the length of guard interval, and CP is length of the cyclic prefix interval, both expressed in the number of sampling periods, i.e. $T_{GI} = GI \cdot T$, $T_{CP} = CP \cdot T$.

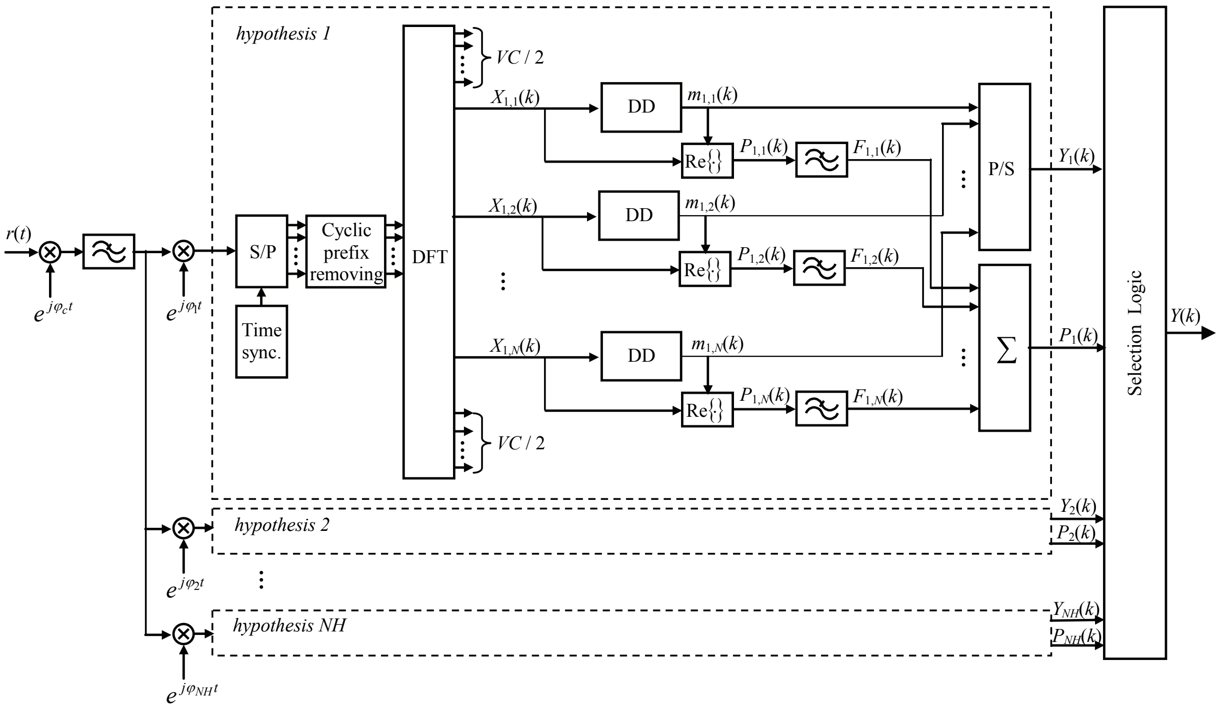

Fig. 1. Proposed model of OFDM/DPSK receiver with reconfigurable structure

There are NH blocks in Fig. 1 marked with dashed lines. These blocks represent different phase hypothesis. The input signal is multiplied by the signal with the corresponding frequency offset φ_{n_h} , where n_h represents number of the hypotheses and $n_h = 1,2,...NH$

$$\varphi_{n_h} = n_h \Delta\varphi - \frac{(NH-1)\Delta\varphi}{2}, n_h = 1,2,...,NH , \quad (4)$$

where $\Delta\varphi$ is algorithm parameter that represents a phase step.

In the corresponding hypothesis block we have S/P block that represents 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 OFDM data frame at the input, and transmitted modulated symbols influenced by the frequency channel response are at the output. In this case we use OFDM demodulator with N subcarriers and discrete Fourier transform. The input is in time, and the output in the frequency domain.

After DFT block we have ordinary differential detection in DD block. Input of the each DD block is X_{n_h,n_c} signal corresponding to hypothesis n_h and OFDM channel n_c ($n_c = 1,2…,N$). At the output we have differential detection decision m_{n_h,n_c} . After the parallel to serial block (P/S) we have OFDM data stream (Y_{n_h}).

The processing is used to determine the signal quality. The block denoted with $\mathrm{Re}\{\cdot\}$ performs the following operation

$$P_{n_h,n_c}(k) = \mathrm{Re}\left\{ X^*_{n_h,n_c}(k-1) X_{n_h,n_c}(k) \times \exp\left(j \frac{2\pi}{M} m_{n_h,n_c} \right) \right\} . (5)$$

To mitigate the effect of noise, $F_{n_h,n_c}(k)$ keeps low pass filtered $P_{n_h,n_c}(k)$ values

$$F_{n_h,n_c}(k) = (1-A) F_{n_h,n_c}(k-1) + A \cdot P_{n_h,n_c}(k) . \quad (6)$$

After calculating the sum

$$P_{n_h}(k) = \sum_{i=1}^{N} F_{n_h,i}(k) , \quad (7)$$

we get the signal quality measure for n_h-th hypothesis.

In the selection logic we first determine the maximum measure of quality

$$P_{\max}(k) = \max_{n_h} P_{n_h}(k) \quad (8)$$

and find the number of maximum measure

$$n_{h,\max} = \arg \max_{n_h} P_{n_h}(k) . \quad (9)$$

Based on the maximum index, selection logic of the output of the receiver selects the corresponding $Y_{n_h,\max}$

$$Y(k) = Y_{n_h,\max}(k) . \quad (10)$$

Numerical results

The performance of the described system is analyzed using Monte-Carlo simulation with one million simulation steps. Simulation parameters are chosen in accordance with set of IEEE 802.11 standards, which does not limit the generality of results. The carrier frequency is 2.4 GHz, the sampling period before DFT block is 10 ns, and the energy per bit to noise power spectral density ratio $E_b / N_0 = 8$. We tested the system for different values of the following parameters: number of OFDM channels (*N*), number of hypothesis (*NH*), and parameter which represents ratio between phase step and bandwidth of OFDM channel $\Delta\varphi / B_c$.

The performance of proposed receiver is compared to the perofrmance of the OFDM/DPSK signal receiver.

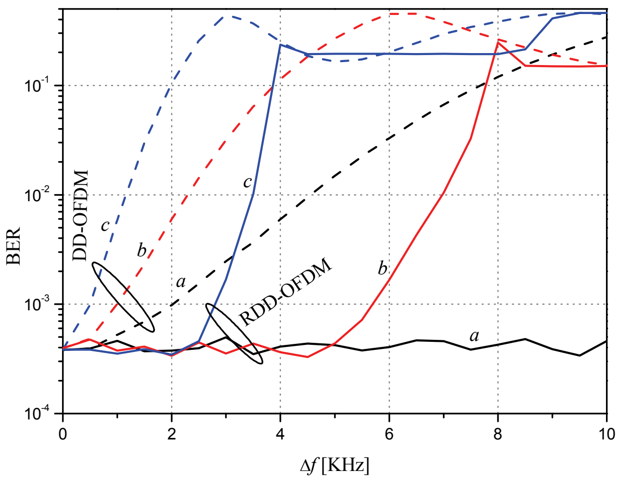

Fig. 2. Bit error probability as a function of frequency offset for OFDM/BPSK system with *N* as a parameter $\Delta\varphi / B_c = 3\%$, $NH = 11$; *a*) *N*=16, *VC* = *CP* = *GI* = 2, *b*) *N*=32, *VC* = *CP* = *GI* = 4, *c*) *N*=64, *VC* = *CP* = *GI* = 8

Fig. 2 shows bit error rate versus frequency offset Δf, with the number of OFDM channels as a parameter. Dashed lines represent differential detection system performances (DD-OFDM) and solid lines represent proposed reconfigurable system performances (RDD-OFDM). Curves labelled with *a*, *b* and *c* represent three different simulated cases. Comparing the corresponding curves one can see a significant improvement in system performance in the presence of frequency offset. For the lowest number of OFDM channels we have the largest difference between DD-OFDM and RDD-OFDM curves. This does not mean that the gain achieved by the OFDM system with higher number of channels has less importance. The OFDM channel bandwidth decreases when then number of OFDM channel increases, which is shown, for different modulation levels, in [12] (the channel bandwidth is 5MHz, 2.5MHZ and 1.25MHz in first, second and third simulated case, respectively). So if we look at improving as a percentage of the bandwidth of the channel then it is equally important in all cases.

Bite error rate as a function of frequency offset with the number of the hypotheses as a parameter is shown on Fig. 3. Dashed line represents performance of DD-OFDM system. There are curves for three different cases, when the number of hypothesis is equal to 5, 11 and 19, respectively. For these analyses, system with 32 OFDM channels is considered. From the figure we can conclude that with the increase the number of hypothesis there is an improvement in the resistance of the system to frequency offset.

Fig. 4 shows bit error probability as a function of frequency offset Δf, with $\Delta\varphi / B_c$ as a parameter, with $E_b / N_0 = 8$ dB, $NH = 11$, and $N = 32$. Dashed line represents performance of system with ordinary differential detection in the receiver. For larger values of $\Delta\varphi / B_c$ ratio, frequency offset has less influence on the system performance. It means that the band within it is possible to achieve satisfying transmission quality is the widest. With the decrease of $\Delta\varphi / B_c$ ratio, 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 larger values of $\Delta\varphi / B_c$ ratio, and the bit error rate near $\Delta f = 0$ Hz is equal for any $\Delta\varphi / B_c$. OFDM/DPSK system with reconfirugarable detection at the receiver is less sensitive to frequency offset for the larger values of parameter $\Delta\varphi / B_c$.

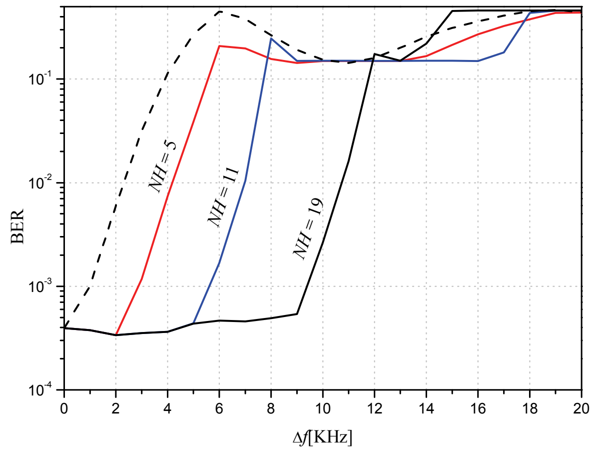

Fig. 3. Bit error probability as a function of frequency offset for OFDM/BPSK system with *NH* as a parameter (N = 32, $\Delta\varphi / B_c$ = 3%)

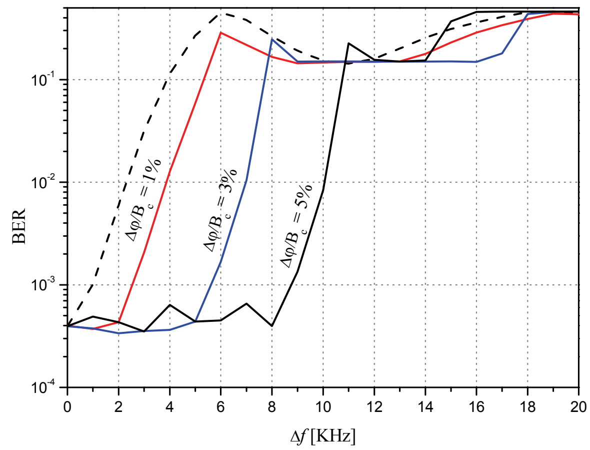

Fig. 4. Bit error probability as a function of frequency offset for OFDM/BPSK system with $\Delta\varphi / B_c$ as a parameter (N = 32, $NH = 11$)

Figs. 3 and 4 show that the expansion of the frequency offsets range with a satisfactory quality of transmission may be achieved in two different ways. The first way is to increase the number of hypotheses, which increases the complexity of the system. The second way is to increase $\Delta\varphi / B_c$ ratio, which does not increase the complexity of the system, but for larger values of $\Delta\varphi / B_c$ there is some instability of the system. This instability may be seen in Fig. 4 for the largest considered value of this parameter ($\Delta\varphi / B_c$ =5%). The extpansion that is obtained is actually a product of these two parameters, *NH* and $\Delta\varphi / B_c$.

The limit in the increase of these two parameters is that their product has to be less than half of the OFDM channel bandwidth.

Conclusions

In this paper we propose a reconfigurable differential detection (RDD) algorithm that can be used for the MDPSK signal reception in the presence of frequency offset. Important feature is that the proposed algorithm does not require pilot symbols, and therefore there is no bandwidth efficiency loss. The analysis shows that the bit error probability of the proposed algorithm is nearly constant in a wide frequency offset range and equal to the error probability for zero frequency offset.

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In this paper we propose a reconfigurable differential detection (RDD) algorithm that can be used for the MDPSK signal reception in the presence of frequency offset. Important feature is that the proposed algorithm does not require pilot symbols, and therefore there is no bandwidth efficiency loss. The analysis shows that the bit error probability of the proposed algorithm is nearly constant in a wide frequency offset range and equal to the error probability for zero frequency offset. Ill. 4, bibl. 12 (in English; abstracts in English and Lithuanian).

S. Stosovic, B. Dimitrijevic, N. Milosevic, Z. Nikolic. OFDM/DPSK sistemos charakteristikų esant dažnio poslinkiui gerinimas naudojant rekonfigūruojamą detektavimo algoritmą // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2012. – Nr. 3(119). – P. 35–38.

Pasiūlytas rekonfigūruojamas diferencinis detektavimo algoritmas, kuris gali būti panaudotas MDPSK signalui priimti esant dažnio poslinkiui. Svarbi yra ta pasiūlytojo algoritmo savybė, kad jis nereikalauja bandomųjų simbolių ir todėl nėra juostos pločio efektyvumo nuostolių. Analizė rodo, kad pasiūlyto algoritmo bitų klaidos tikimybė yra artima konstantai plačiame dažnių poslinkio ruože ir lygi nulinio dažnio poslinkio klaidos tikimybei. Il. 4, bibl. 12 (anglų kalba; santraukos anglų ir lietuvių k.).