Frequency Offset Influence on OFDM/MDPSK System Performance

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Abstract - **In this paper, basic characteristics of OFDM systems are presented. Characteristics of OFDM systems with MDPSK modulation in every channel are simulated. For simulation and analysis of OFDM systems performance we used simulation environment designed for this purpose. We stressed OFDM frequency offset. We analyzed influence of OFDM system parameters on system performance for various values of frequency offset, parameter *M* and channels number.**

Keywords - **orthogonal frequency-division multiplexing (OFDM), M-ary differential phase-shift keying (MDPSK), frequency offset, frequency synchronization.**

I. Introduction

Orthogonal Frequency Division Multiplexing (OFDM) is the special kind of multicarrier modulation, where we simultaneously transmit a block of data symbols 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).

In the OFDM system, the ISI problem caused by delay spread of dispersive fading channels can be overcome by inserting a guard interval between adjacent OFDM symbols. 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 the 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, MDPSK modulation in the temporal direction has good performance as phases of multiplicative distortions are assumed to be constant during consecutive OFDM symbol intervals.

The error performance of MDPSK/OFDM is degraded and the irreducible error rate is introduced at fast fading.

Data transfer with OFDM system has many advantages:

-High spectral efficiency due to nearly rectangular frequency spectrum for high numbers of subcarriers.

-Simple digital realization by using the FFT operation.

-Low complex receivers due to the avoidance of ISI and ICI with a sufficiently long guard interval.

-Flexible spectrum adaptation can be realized.

-Different modulation schemes can be used on individual subcarriers which are adapted to the transmission conditions on each subcarrier.

There are also certain disadvantages:

-Multi-carrier signals with high peak-to-average power ratio (PAPR) require high linear amplifiers. Otherwise, performance degradations occur and the out-of-band power will be enhanced.

-Loss in spectral efficiency due to guard interval.

-More sensitive to Doppler spreads then single-carrier modulated systems.

-Phase noise caused by these imperfections of the transmitter and receiver oscillators influence the system performance.

-Accurate frequency and time synchronization is required.

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 5-GHz local area networks (IEEE 802.11a in US and HIPERLAN in Europe) [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]. OFDM can also serve as an alternative transmission method to digital European cordless telephone (DECT)-like digital cordless systems [6].

In this paper, we presented the performance of OFDM system with MDPSK modulation in every channel. For this purpose we designed a special simulation platform and analyzed the influence of OFDM system parameters on

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system performance for various kinds of MDPSK mudulations. The performance of OFDM/MDPSK system in the presence of frequency offset is also showed.

II. System Model

Models of OFDM transmitter and receiver are shown in Figures 1. and 2., respectively.

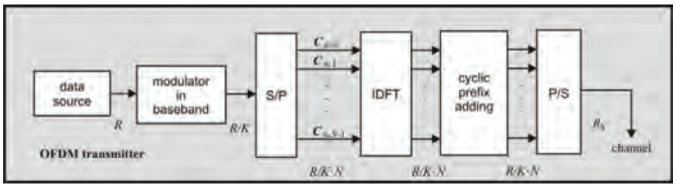

Fig 1. OFDM Transmitter

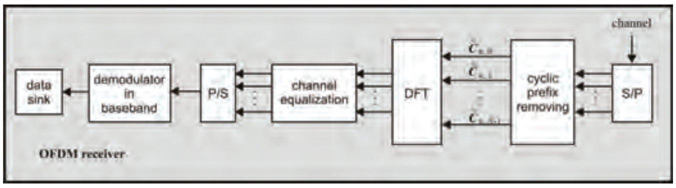

Fig 2. OFDM receiver

A. OFDM Transmitter

Typical OFDM transmitter consists of the following components:

Data source - Output is the sequence of uncorrelated random binary symbols ("0" i "1") with bitrate *R*.

Modulator in the baseband – Input is the sequence of binary symbols, and modulated symbols are at the output, chosen from MPSK, MDPSK or 16-QAM constellation, and the symbol rate at the output *R/K*. Modulator function is to map *K* binary input symbols to a modulated symbol according the signalization scheme.

S/P (serial to parallel converter) – output symbol rate is *R/K·N* and the frame of *N* symbols is formed.

IDFT (Inverse DFT) - *N* modulated input symbols are transmitted over a OFDM subcarrier. OFDM data frame of length *N* is at the output. Output symbol rate is *R/K·N*. OFDM modulator with *N* subcarriers is implemented using IDFT. Input of this block is in the frequency, and output in the time domain.

Cyclic prefix adding: OFDM data frame is at the input, and cyclic extended OFDM data frame with prefix consisting of the last *L* frame symbols (*L* is maximum delay in the channel). This is efficient against the multipath. Output symbol rate is *R*/*K·N*.

P/S (parallel to serial converter) – transforms parallel input data stream consisting of *N* symbols into serial stream. Output rate is $R_s = R(1+L/N)/K$.

B. OFDM Receiver

DFT: received and reconstructed OFDM data frame is 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 descrete Fourier transform. Input is in time, and output in the frequency domain.

Channel equalization: received symbols and frequency channel estimations on OFDM subcarrier frequency are at the input, and reconstructed modulated symbols are at the output. *Zero-forcing equalization* of OFDM subcarrier is performed here in the frequency domain. Only the subcarriers above the certain predefined threshold are equalized, in other cases they are unreliable (very low signal to noise ratio (SNR)).

Data Sink: reconstructed binary information is on the input. Here is performed processing typical for the received information.

III. OFDM System In The Presence Of Frequency Offset

In the case of ideal synchronization between transmitter and receiver, OFDM signal in the receiver, after FFT (Fast Fourier Transformation) block, can be represented as [7]:

$$Y_{i,k} = X_{i,k} H_{i,k} + N_{i,k} \tag{3}$$

where $X_{i,k}$ is a complex data symbol in baseband, $H_{i,k}$ is transfer function of *i*-th channel in *k*-th signalization interval and $N_{i,k}$ is noise in *i*-th subchannel in *k*-th signalization interval. Equation (3) shows that ideal synchronized OFDM system can be represented as a set of parallel Gaussian channels, meaning that OFDM enables that frequency selected channel is equivalent to the set of mutually orthogonal subchannels with frequency flat fading. However, in the presence of frequency offset, subcarriers orthogonality can be destroyed.

In the indoor case, Doppler offset can be neglected, but there is a frequency offset between transmitter and receiver oscillators. Frequency offset is mathematically described with frequency offset δf and phase offset θ in the lowpass equivalent signal. In the presence of frequency offset, signal in the receiver, after FFT block, can be represented as [7]:

$$\begin{aligned} Y_{i,k} &= X_{i,k} H_{i,k} \,\mathrm{sinc}(\delta f T)\cdot \\ &\exp\{ j[\theta + 2\pi \delta f\,(kT_s + T/2] \} + N'_{i,k} \end{aligned} \tag{4}$$

where T is effective part of symbol duration (within guard interval),

T_s is full OFDM symbol duration, $N'_{i,k}$ is the overall noise of *i*-th channel in *k*-th signalization interval, including additive noise, due to ICI.

From equation (4) it can be seen, that frequency offset influences only phase change between two OFDM symbols, if frequency offset is constant. So, in the slowly varying flat fading channel, where channel and frequency offset estimation are periodically done, cumulative effect of frequency offset becomes very important, meaning that for every following OFDM symbol in the frame estimation error increases.

Frequency offset can appear because of the mismatch between transmitter and receiver oscillator or as the consequence of Doppler offset. Interference among subcarriers (ICI – Intercarrier Interference), due to frequency offset, degrades system performances, [7]. Therefore, 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, [8], [9]. Second group of estimation methods is based on use of special pilot sequences for frequency estimation offset [10], [11].

IV. Performance Analysis

Simulations of OFDM system were performed using specially developed environment at 2.4 GHz, without protective coding. Three different cases were simulated. In the first case, number of subcarriers (*N*) is 16, number of virtual channels (*VC*) is 2, number of channels used for cyclic prefix is 2 and number of channels used for guard interval (*GI*) is 2. In second case number of subcarriers is 32, number of virtual channels is 4, number of channels used for cyclic prefix is 4 and number of channels used for guard interval is 4. And finally, in the third case, number of subcarriers is 64, number of virtual channels is 8, number of channels used for cyclic prefix is 8 and number of channels used for guard interval is 8.

We used MDPSK modulation for each channel and tested OFDM system performances as a function of parameter *M* (level of DPSK modulation).

Figs. 3, 4 and 5 show OFDM system symbol error rate (*SER*) as a function of the energy per bit to noise power spectral density ratio (E_b/N_0), for different values of parameter *M*, in the presence of frequency offset, Δf=150 kHz (dashed lines) and without frequency offset (solid lines). The frequency offset is not estimated and corrected in simulations.

Fig. 3 shows OFDM system performances, in the first case (*N*=16, *VC*=*GI*=*CP*=2), versus E_b/N_0. From the Fig. 3, we can see that system performances depend of parameter *M* and decrease with increase of parameter *M*. Also, symbol error rate difference in the presence of the frequency offset compared to the symbol error rate without frequency offset increases with parameter *M* increase.

Similarly, Figs. 5 and 6 show performance of system in the second and third case versus E_b/N_0 with *M* as a parameter, respectively.

From the Figs. 3, 4 and 5, we can conclude that the frequency offset causes a performance drop compared to the ideal synchronizating system, and the performance drop rises with the increase of DPSK modulation level (*M*) and the number of subcarriers (*N*).

When the number of subcarriers and parameter *M* are greater, system performances decrease and the system stops operating, that correspondents to OFDM characteristics.

Fig. 6 shows symbol error rate versus frequency offset Δf, for system in the first case and *M* as a parameter. For smaller values of parameter *M*, frequency offset has less influence on the system performances. It means that, the band within it is possible to achieve satisfying transmission quality is the widest. With increase of parameter *M*, the influence of frequency offset on transmission quality also increases.

In the Figs. 7 and 8 we presented symbol error rate versus frequency offset for system in second and third case, respectively. Parameter *M* influences the symbol error rate in the same way as in Fig. 6.

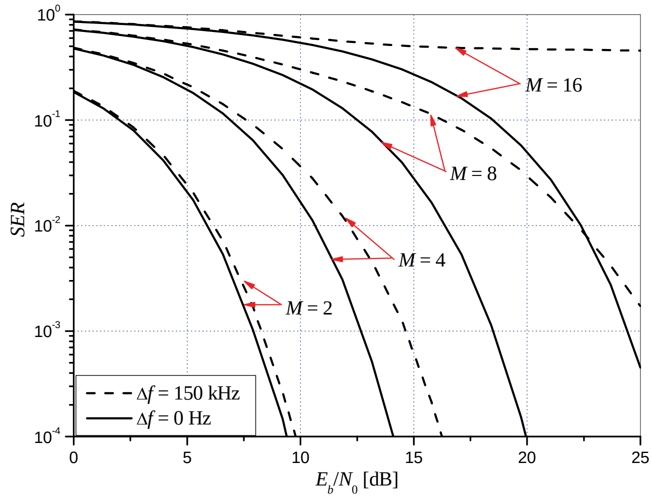

Fig. 3. Symbol error rate versus E_b/N_0 for *N*=16 and *VC*=*GI*=*CP*=2

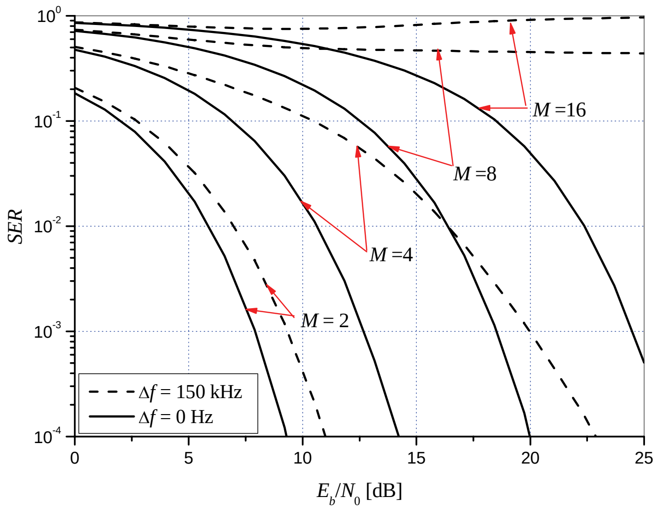

Fig. 4. Symbol error rate versus E_b/N_0 for *N*=32 and *VC*=*GI*=*CP*=4

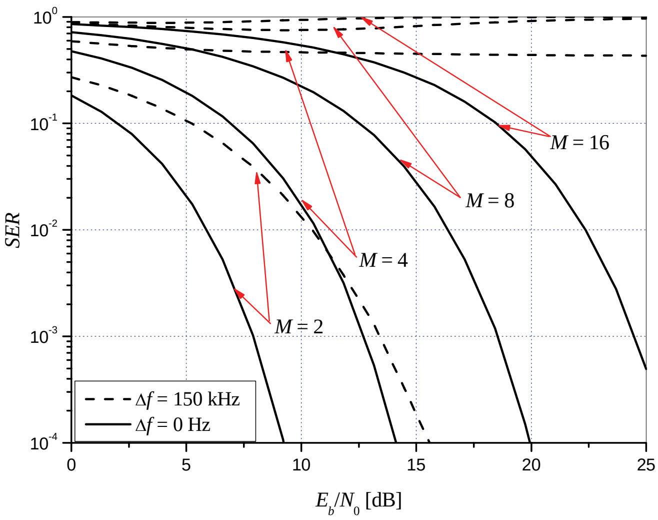

Fig. 5. Symbol error rate versus E_b/N_0 for *N*=64 and *VC*=*GI*=*CP*=8

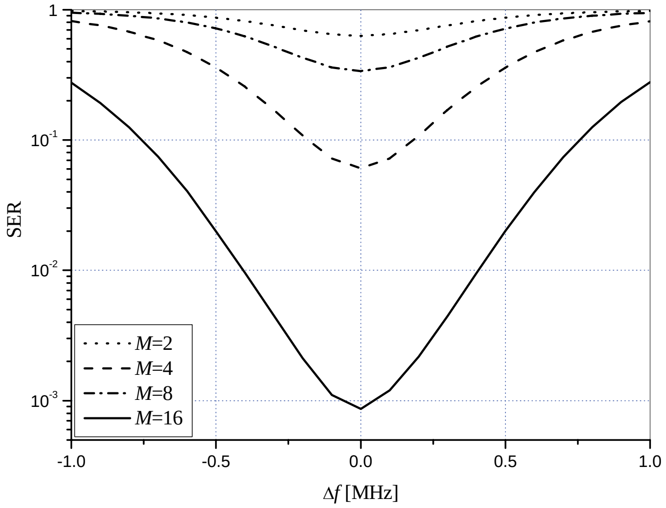

Fig. 6. Symbol error rate versus frequency offset Δf for N=16 and VC=GI=CP=2

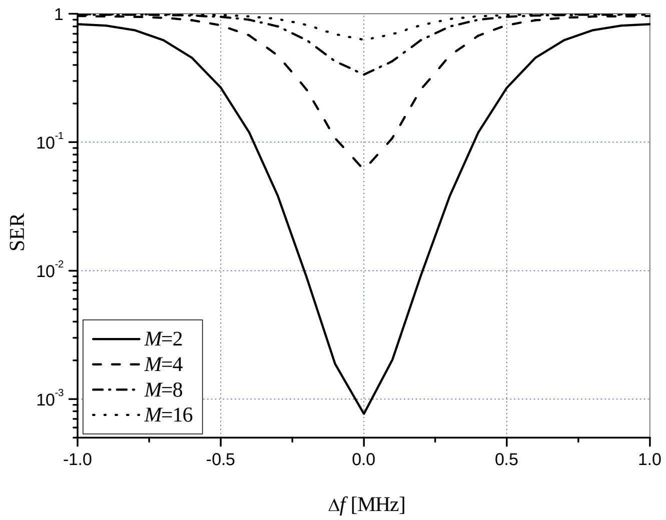

Fig. 7. Symbol error rate versus frequency offset Δf for N=32 and VC=GI=CP=4

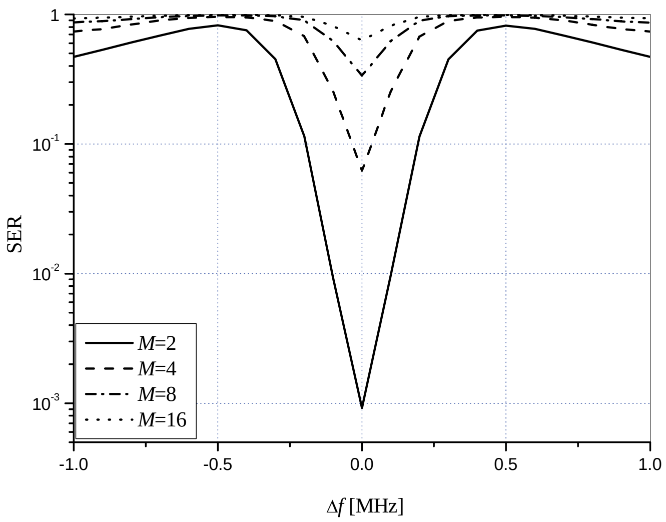

Fig. 8. Symbol error rate versus frequency offset Δf for N=64 and VC=GI=CP=8

Parameter E_b/N_0 for the Figs. 6, 7 and 8 is 8dB. From the Figs. 6, 7 and 8 we can conclude that number of subcarriers influences the OFDM system performances with MDPSK modulation. Frequency offsets range where there is a satisfying transmission quality becomes narrower with the incerase of the number of subcarriers and the number of modulation levels.

CONCLUSION

Own simulation environment is developed and used for presenting the basic characteristics of OFDM system. Analysis of OFDM parameters influence to system performances for different values of frequency offset is performed. We also analyzed the influence of the modulation level of MDPSK modulation on the system performances in the presence of frequency offset. It was shown that in the presence of frequency offset the modulation level much influences the system performances. Because of this influence it is desirable to use estimation and frequency offset correction, and also to carefully choose values for the number of subcarriers and modulation level.

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