PERFORMANCE OF MULTUSER OFDM DOWNLINK SYSTEM IN MULTIPATH FADING CHANNEL

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Abstract - Multiuser orthogonal frequency division multiplexing downlink system is analyzed. The combination of multiple access techniques, frequency-division multiple access (FDMA) and time-division multiple access (TDMA), is applied. A set of subcarriers is assigned to each user, in accordance with user's demands for allocated bit rate. Performance of such system is simulated and compared to performance of OFDM system without particular multiple access scheme in multipath fading channel.

1. INTRODUCTION

Nowadays, demands imposed for wireless communications are increasing. Although current mobile communications systems are primarily voice based applications, requiring only low data rates, future applications for wireless systems will require much higher data rates, demanded by services like Internet access, e-mail, computer networking and video-conferencing. System capacity of such networks must be much higher than capacity of present networks in order to support these higher user data rates.

Many of these services require extreme grow in downlink bandwidth, keeping in between, demands for uplink resources on nearly the same level as earlier services. This means that for uplink older and simpler modulation techniques and protocols can be used, while for the downlink the more sophisticated ones have to be found. The later is considered in this work.

Recently, intense interest has been focused on modulation techniques that can provide broadband transmission over wireless channels for applications including wireless multimedia, wireless Internet access and future-generation mobile communication systems. One of the main requirements on the modulation techniques is the ability to combat intersymbol interference (ISI), a major problem in wideband transmission over multipath fading channels. Multi-carrier modulation techniques, including orthogonal frequency-division multiplexing (OFDM) are among the most promising solutions to this problem. Multiuser OFDM is a new modulation method that can potentially greatly increase the capacity of wireless communications systems, and additionally improve user access reliability.

OFDM systems are, however, more sensitive to synchronization errors and non-linear distortions than single-carrier systems, but these problems can be circumvented as with advances in RF and signal processing industry. The crucial mark for the system in its performance is commonly used work environment for a wireless system i.e. in the multipath fading channel. This was the main reason for us to perform a simulation of such system. Getting results from such simulation can establish solid ground for further work on real system.

In order to establish a background for a real system some kind of multiple user access scheme must be chosen. From single-carrier systems a variety of multiple access techniques is known, such as TDMA, FDMA, and CDMA or combinations of them. Basically, these techniques can also be adapted to multicarrier transmission but some peculiarities have to be taken into account. More thorough analysis of the problem can be found in [7]. In this paper, we described a combination of FDMA and TDMA, as the multiple access method for proposed multiuser OFDM system and we have also presented some results comparing performance of OFDM system without multiple access scheme to proposed one.

The paper is organized as follows. The proposed system in described in Section 2. OFDM system architecture and multiple access scheme are described in Subsection 2.1 and 2.2, respectively. In Subsection 2.3, downlink scenario is considered. The applied channel model is presented in Section 3. The simulation results of proposed system and its performance versus multipath fading environment are in Section 4. The paper is concluded with Section 5, which summarizes the main results.

2. SYSTEM MODEL

2.1. OFDM System

OFDM uses the spectrum much more efficiently than FDMA, for example, with which it is similar. OFDM splits the available bandwidth into many narrow band channels. The carriers for each channel are made orthogonal to one another, allowing them to be spaced very close together, with no overhead for filtering out the signals from adjacent channels. Since OFDM systems transmit data in parallel, they have larger symbol intervals, and the frequency overlapping gives a system with high spectral efficiency. Orthogonal subcarriers are achieved by using inverse discrete Fourier transform (IDFT) at the transmitter and the discrete Fourier transform (DFT) at the receiver end.

![Fig. 1 An OFDM system basic architecture](image-url)
Basic architecture of the system is depicted at the Fig 1. The long symbol reduce the problem of Inter Symbol Interference (ISI). When an OFDM signal passes through a time dispersive channel the received signal will suffer from intersymbol interference. However, if we insert Cyclic Prefix (CP), longer than the length of the channel impulse response, all ISI will be removed by deleting the CP before the DFT in the receiver. The cost of using it CP is a reduction in data rate and loss of power.

Fig. 1 illustrates the OFDM transmission technique, [1] and [2]. The complex data symbols \( x_{k,m} \) are modulated on \( N \) subcarriers by IDFT, and the last \( L \) samples are copied and put as preamble (cyclic prefix, CP) to form the OFDM symbol. This data vector is serially transmitted over a channel. At the receiver, the cyclic prefix is removed, and the signals \( x_{k,m} \) are the result of demodulation DFT. Therefore, the symbol time for the OFDM symbol is \((N-L)\) times longer than the symbol time for single data symbol, where \(N\) is the number of points in IDFT. In this way it is possible to extend the OFDM symbol time, and get it much longer than the maximum excess delay, thereby making the echoes affect only the first part of the symbol, but not more. In the particular case we have used \(N=112\) and \(L=128\) for the simulation.

2.2. Multiple Access Scheme

In this paper we have used a combination of FDMA and TDMA, as the multiple access method for multistandard OFDM system, [2], [3] and [7]. The resource management is according to needs of particular user. The available spectrum is subdivided in bands of adjacent subcarriers. Each band consists of equal number of subcarriers and this determines lowest data rate available per user. If particular user has demand for larger data rates this can be easily achieved by assigning to him several sub-bands at the instant. Within each of these bands, a TDMA scheme is applied. Users are thus separated both in frequency (each user is allocated to a particular sub-band) and in time (each user is allocated to a particular time slot).

![Fig. 2. An example of combination FDMA-TDMA multiple access](image)

On Fig. 2 an example of proposed multiplex access scheme is presented with cluster size of 4 subcarriers by 3 symbol intervals. Each color in the grayscale depicts different user. It is easily seen that to each user 4 subcarriers are assigned for 3 symbol periods. If some users have bigger demands for throughput than others clusters of larger size can be assigned to the user for the instant. Assigning different sub-bands to a user in consecutive time slots diminishes effects of frequency selective fading environment.

In the simulated system, the minimum access entity (cluster size) is 16 adjacent subcarriers. For higher data rates, users request more transmission blocks. In performed simulations it is supposed that all users have the same needs, and that each user is going to get some other transmission block in next five consecutive OFDM symbols.

2.3. Downlink Scenario

The uplink and downlink scenario are proposed separately in [3], [6] and [7]. In [7] multistandard OFDM system is analyzed for both scenarios. In others, the asymmetrical wireless data access is considered. The Enhanced Data for GSM Evolution (EDGE) is considered for uplink, and wideband OFDM (WOFDM) for downlink scenario. In both cases we have the similar frame structure for communication between base station (BS) and mobile user (MS).

In this paper only downlink scenario is considered. Base station transmits OFDM symbols that contain data for all users. Each user gets assigned set of subcarriers, i.e. transmission block, containing data that belong to him. The user demodulates the signals with DFT and chooses the data modulated on carriers assigned to him. Resource assignment is performed by the base station and automatically presented to users in the preamble of the frame.

We suppose that all users have same needs for bit rate. Each transmission block is assigned to one user and each user gets one transmission block. The transmission blocks are divided to users accidentally.

3. CHANNEL MODEL

The channel is modeled as a time varying FIR-filter of length M. Hence the channel impulse response is:

\[
\mathbf{h}(t) = \sum_{i=0}^{M} b_i \delta(t - \tau_i)
\]

where \(h_i\) is the attenuation and \(\tau_i\) is the delay of the \(i\)th path. In our model, it is assumed that for \(i=0\) we have signal received by direct path and hence \(h_0\) loss Rayleigh distribution of amplitude. Also we assumed to have the channel model with wide sense stationary uncorrelated scattering, (WSSUS). Because of that all coefficients \(h_i (i>0)\) are independent from each other and have Rayleigh distribution of amplitude, varying according to Doppler spectrum. In the simulated system, the velocity of mobile user is assumed to be \(v=344\text{ km/h}\), and corresponding maximum Doppler shift for central frequency \(f_c=1\text{ GHz}\) is \(f_d=100\text{ Hz}\).

The simulated channel model has been proposed by Jakes, [4], and simulated channel type is "mural area", specified by GSM 05.85, ETSI 300 579.

The applied model of multipath channel is described in Table 1.
Table 1. Characteristics of Channel Environment

<table>
<thead>
<tr>
<th>Tap</th>
<th>Relative Delay (μs)</th>
<th>Average Power (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>2</td>
<td>0.2</td>
<td>2.0</td>
</tr>
<tr>
<td>3</td>
<td>0.4</td>
<td>-10.0</td>
</tr>
<tr>
<td>4</td>
<td>0.6</td>
<td>-20.0</td>
</tr>
</tbody>
</table>

The first path has the Rician distribution of amplitude, and the other paths have the Rayleigh distribution. For the first path, different carrier-to-multipath power ratios \( K \) have been analyzed. \( K \) denotes the ratio of power of the signal received on direct path and total power of signals received by indirect paths.

4. SIMULATION RESULTS

In this paper we simulate the OFDM system with \( N=512 \) subcarriers. The length of cyclic prefix is \( L=128 \). The minimum access entity is 10 adjacent subcarriers during five consecutive OFDM symbols. In accordance with that, we have 22 entities at disposal for users. Channel response is modeled as described in equation (1) with addition of white Gaussian noise. The transmission and multiple access features of one multiuser OFDM system, which is in accordance with proposed system's parameters, are described in Table 2.

Table 2. The transmission and multiple access characteristics of the system

<p>| | |</p>
<table>
<thead>
<tr>
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<tbody>
<tr>
<td>Central frequency</td>
<td>2GHz</td>
</tr>
<tr>
<td>Uplink/Downlink</td>
<td>5MHz/5MHz</td>
</tr>
<tr>
<td>bandwidth</td>
<td></td>
</tr>
<tr>
<td>Inter-carrier spacing</td>
<td>9.77kHz</td>
</tr>
<tr>
<td>Symbol length</td>
<td>102.4μs (512 samples)</td>
</tr>
<tr>
<td>Cyclic prefix</td>
<td>23.6μs (128 samples)</td>
</tr>
<tr>
<td>Transmission block</td>
<td>16 subcarriers x 5 symbols</td>
</tr>
<tr>
<td>Data rate</td>
<td>multiples of 234.375kbps</td>
</tr>
<tr>
<td>Modulation</td>
<td>DQPSK</td>
</tr>
<tr>
<td>Maximum data rate</td>
<td>7.5Mbps</td>
</tr>
</tbody>
</table>

The performance of coherent modulation schemes depends on the quality of the channel estimation. We implemented differential encoding between adjacent subcarriers of the same OFDM symbol, employing DQPSK modulation. It is possible to implement differential encoding between corresponding subcarriers of consecutive OFDM symbols. In both cases channel-induced phase rotation is only affected by differential channel phase distortion between two consecutive subcarriers or two consecutive OFDM symbols, rather than by channel phase distortions' absolute value, [5] and [7].

On Fig.3, we simulate typical OFDM system without particular resource allocation scheme and one-tap channel model with Rician distribution of amplitude. The bit-error-rate (BER) performance curves versus channel signal-to-noise ratio (SNR) for different values of \( K \) are presented. For stronger signal in line-of-sight (LOS) signal, i.e. greater \( K \), the system performance is better. For \( K=0 \) the Rayleigh distribution of amplitude is analyzed.

Fig.3. BER versus SNR for OFDM system with Rician fading channel and different fading parameters \( K \)

On Fig.4, it analyzed the system under the same conditions as on Fig.3, but not with one-tap channel model. The channel model proposed in Table 1. has been applied. The BER performance this time is worse than in previous example because of the influence of multipath propagation.

Fig.4. BER versus SNR for OFDM system in "rural area" fading channel and different fading parameters \( K \)

The downlink scenario of proposed multiuser OFDM system with FDMA/TDMA resource allocation scheme has been simulated. On Fig.5 are the BER performance curves versus channel SNR performance for downlink are given. The channel model is one proposed in Table 1. The different values of parameter \( K \) are considered. Slight improvements in BER performance compared to previous example are due to reduction of frequency selectivity channel influence, because now we have 32 smaller frequency bands instead of big one.

Fig.5. BER versus SNR for OFDM system in "rural area" fading channel and different fading parameters \( K \)
On Fig.5, the BER performance for two different multiple access schemes are compared. The first multiple access scheme is one already proposed based on FDMA/TDMA. The second is based on first one, but without possibility for changing frequency clusters in time, i.e. user transmits all symbols in one frequency cluster. This can be referred to as multiuser TDMA transmission scheme. The maximum BER per user curves are shown, and we note better performance of the multiple access scheme employing FDMA/TDMA, which is similar to some kind of frequency hopping. With this multiple access scheme all users have almost the same bit-error-rate, because of almost equal distribution of frequency selectivity channel influence on all users. For greater K the difference between maximum BER curves are less significant.

![Fig.5. BER versus SNR for multiuser OFDM system in “rural area” fading channel](image)

Fig. 5. BER versus SNR for multiuser OFDM system in “rural area” fading channel

5. CONCLUSIONS

The single multiuser OFDM system is analyzed in multi-path fading environment. The type of applied channel is “rural area”, with Rician and Rayleigh distribution of tap amplitudes. The system has the better performance for stronger LOS signal. The system performance in downlink scenario is with slight improvements, due to reduction of frequency selectivity channel influence. Multiuser OFDM downlink system is with better performance for combination of FDMA and TDMA as multiple access scheme, then in the case where the frequency channel assigned to the user doesn’t change in time.

REFERENCES


PERFORMANSE VIŠEKOMUNIKACIJSKOG OFDM SISTEMA U POVRAĆNOM KANALU SA FEDINGOM USLED VIŠESTRUKO PROPAGACIJE

Ivona Simić, Boris Simić