Simulation, Modeling, and Performance Analysis of IEEE 802.16e OFDMA Systems for Urban and Rural Environments

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Abstract—In this paper we investigate the performance of IEEE 802.16-2005 OFDMA system with high order QAM/QPSK mapping in the presence of high SNR values that are found both in Urban and Rural Environments. We consider OFDMA scheme with an AWGN channel and analyze their performance in terms of the BER in the system.

I. INTRODUCTION

Mobile networks based on the IEEE 802.16-2005 standard are promising candidates for providing broadband wireless access to mobile users. Due to the flexibility of the physical layer definition based on Orthogonal Frequency Division Multiple Access (OFDMA), it is possible to adjust the networks according to IEEE 802.16e to meet different requirements, e.g., system bandwidth. However, these networks cannot guarantee a reliable transmission in scenarios with frequency reuse of 1 to users at the cell border which achieve only poor Signal to Noise Ratio (SNR) conditions due to the high amount of interference from neighbouring cells.

In this paper we investigate the impact of critical OFDMA parameters for different PSK/QPSK modulation schemes in the presence of high SNR values that are found both in Urban and Rural Environments.

This paper is organized as follows: Section 2 describes the WiMAX system level model; Section 3 presents an overview about the simulation model used for the investigation with description of the performed link and system level simulations; Section 4 presents the simulation results; and the conclusions are given in Section 5.

II. IEEE 802.16E SYSTEM MODEL

The IEEE 802.16-2005 [1] specification defines multiple modulation schemes to extend broadband wireless access (BWA) from the local area network (LAN) to the metropolitan area network (MAN). The different schemes operate between 2 and 66 GHz. At the higher frequencies, line of sight is a necessity. This requirement eases the effect of multipath, allowing for wide channels, typically greater than 10 MHz in bandwidth. This gives IEEE 802.16 the ability to provide very high capacity links on both the uplink and the downlink. At the lower frequencies, line of sight is not required, giving other tradeoffs. Adaptive burst profiles (modulation and forward error correction (FEC)) are used to further increase the typical capacity of 802.16 systems with respect to older technology. The MAC was designed to accommodate different PHYs for the different environments. The single service provider PHYs are designed to accommodate either Time Division Duplexing (TDD) or Frequency Division Duplexing (FDD) deployments, allowing for both full- and half-duplex terminals in the FDD case. The OFDM PHYs are designed for TDD.

In the time domain, an OFDMA symbol is defined by the useful symbol period Tb and a guard period Tg. A copy of the last Tg of the useful symbol is placed at the front and is referred to as the cyclic prefix (CP). This is used to help with multi-path effects. The symbol structure in the time domain is shown in Fig. 1.

Figure 1 OFDM symbol time structure.

In the frequency domain, an OFDMA symbol is made up of a number of subcarriers; depending upon the FFT size used. In 802.16-2005, the FFT sizes can be 128, 512, 1024 or 2048, which facilitates the use of the various channel bandwidths. There are three types of subcarriers employed: data subcarriers (for data transmission), pilot subcarriers (for various estimation purposes) and null carriers (no transmission at all, for guard bands and DC carriers). The active subcarriers are divided into subsets of subcarriers called subchannels.

Three primitive parameters characterize the OFDMA symbol:

BW: This is the nominal channel bandwidth.

n: Sampling factor. This parameter is used to determine the carrier spacing and the useful symbol time. Note that this value depends on the selected bandwidth.
G: This is the ratio of CP to the useful time.

From the primitive values above, the following parameters may be derived:

\[
F_s = \text{floor}\left(\frac{n \cdot BW}{8000}\right) 8000
\]

Subcarrier spacing: 
\[
\Delta f = \frac{F_s}{N_{FFT}}
\]

Useful symbol time: 
\[
T_b = \frac{1}{\Delta f}
\]

CP Time: 
\[
T_g = G \cdot T_b
\]

OFDM Symbol Time: 
\[
T_s = T_b + T_g
\]

The sampling factor \(n\), in conjunction with the bandwidth \(BW\) and the size of the FFT \(N_{FFT}\) determines the subcarrier spacing \(\Delta f\). In general, careful selection of the carrier spacing ensures that each subcarrier is orthogonal (linearly independent) to the other subcarriers. Orthogonality can be achieved by ensuring that the carrier spacing is equal to the reciprocal of the useful symbol time \(T_b\).

The 802.16-2005 OFDMA system is a point-to-multipoint system, which supports a frame structure with two duplexing modes — TDD and FDD. In licensed bands, the duplexing method may be TDD or FDD. In addition, FDD SSs may be HFDD. In license-exempt bands, the duplexing method is TDD.

The OFDMA system supports partial usage of subchannels (PUSC), where some of the subchannels are allocated to the transmitter; and full usage of subchannels (FUSC), where all the subchannels are allocated to the transmitter. Note that FUSC is an exclusively downlink feature. The OFDMA frame may include multiple zones, each of which is composed of a integer number of bursts. The maximum number of allowed zones in the downlink is eight, while for the uplink it is three. Table I displays the available zones in an OFDMA system and their allocation in downlink and uplink.

<table>
<thead>
<tr>
<th>OFDMA Zone Type</th>
<th>Downlink</th>
<th>Uplink</th>
</tr>
</thead>
<tbody>
<tr>
<td>PUSC</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FUSC</td>
<td></td>
<td></td>
</tr>
<tr>
<td>AMC</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The TDD frame contains a downlink subframe and an uplink subframe, as illustrated in Fig. 2. Each frame begins with a preamble followed by a downlink transmission period and uplink transmission period. In each frame, the TTG and RTG are inserted between the downlink and the uplink and at the end of the frame, respectively. This is done to allow the BS to turn around.

In the FDD mode, there are separate uplink and downlink subframes that reside on different frequencies. The frame structures are the same as the downlink and uplink subframes defined for TDD.

Each OFDMA symbol data is coded and modulated before it is assigned to a subcarrier. The channel coding has three stages-data randomization, forward error correction (FEC) and interleaving. The forward error correction is a concatenation of a Reed-Solomon outer code and a convolutional inner code with optional turbo coding. The encoded data bits are interleaved and passed to a BPSK, QPSK, 16QAM or 64QAM modulator. The modulated output is then mapped to allocated active subcarriers called subchannels. Once the OFDMA symbol has been formed, an inverse FFT is performed to obtain a signal in the time domain. Fig. 3 illustrates the block diagram of an OFDMA signal generator.

III. THE SIMULATION MODEL

Throughout this paper, a system according to IEEE 802.16e specification is assumed [1]. The FFT size is 2048. The main system parameters are given in Table 2. The network design is chosen to improve the reliability of the transmission at the cell border in scenarios with high SNR. Therefore, a synchronized network in TDD and the default PUSC mode is assumed. The frame structure is built according to IEEE 802.16e specification. All BSSs are synchronised and 50% of the frame duration is used for the DL subframe. Therefore, there is no interference between DL and UL although TDD is assumed. On average three OFDMA symbols at the beginning of each frame are assumed to be used for control information including preamble, DL- and UL-map. Figure 4 shows the Simulation Environment.
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### TABLE II. SYSTEM MODEL PARAMETERS

<table>
<thead>
<tr>
<th>Available bandwidth</th>
<th>10, 20 MHz</th>
</tr>
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<tbody>
<tr>
<td>Centre Frequency</td>
<td>2.4, 5.8 GHz</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Modulations</th>
</tr>
</thead>
<tbody>
<tr>
<td>QPSK, 16QAM, 64QAM, QPSK-1/2, 16QAM-3/4, 16QAM-1/2, 64QAM-2/3, 64QAM-3/4</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Frame duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>5,10,20 ms (50 % for DL subframe)</td>
</tr>
</tbody>
</table>

The analysis is done with the Aeroflex IQCreator [3] and ADS 2006 [4]. The analysis model contains a hexagonal cell grid with at least two tiers of interfering cells. A wrap around model is applied to avoid border effects when calculating interference [5].

A Full Buffer traffic model (FB) is assumed so that each user has always data to transmit. No Quality of Service requirement is considered. It was shown in [6] that FB leads to too optimistic results but this is an upper bound for a fully loaded system. If at least one user is assigned to a BS, all resources of the BS will be used and the BS will transmit with maximum power.

An interference limited system is considered, i.e., additive noise has no dominant influence on the SINR of the users. Convolutional coding and interleaving is assumed as specified in [2]. The receiver contains a Viterbi-algorithm with soft input and hard output [7]. It is assumed that an FEC block is decoded correctly as long as all bits contained in the FEC block are decoded correctly. The FEC block error probability from link level simulations are mapped to One-PS by effective SNR mapping as described in [2]. The effective SNR mapping requires AWGN in the link level while fast fading is considered on system level.

### IV. SIMULATION RESULTS

In this section, the simulation results for the systems described in section 3 are presented.

### TABLE III. SIMULATION RESULTS FOR FFT=2048, BW=20MHz, G=1/8, FRAME LENGTH=5ms, DOWNLINK MODULATION=64QAM-1/2, UPLINK MODULATION=16QAM-1/2, SNR=30dB

<table>
<thead>
<tr>
<th>Noise Bandwidth (% of sample rate)</th>
<th>Peak (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 (SNR=0 dB)</td>
<td>11.15</td>
</tr>
<tr>
<td>5</td>
<td>11.10</td>
</tr>
<tr>
<td>10</td>
<td>11.17</td>
</tr>
<tr>
<td>20</td>
<td>11.20</td>
</tr>
<tr>
<td>30</td>
<td>11.16</td>
</tr>
<tr>
<td>40</td>
<td>11.14</td>
</tr>
</tbody>
</table>
Figure 5 Probability (%) versus Peak to Average Power (dB) for: FFT=2048, BW=20MHz, G=1/8, Frame Length=5ms, DownLink Modulation=64QAM-1/2, Uplink Modulation=16QAM-1/2, SNR=0dB.

Figure 6 Peak (dB) versus Noise Bandwidth for Frame Length=5ms.

Figure 7 Probability (%) versus Peak to Average Power (dB) for: FFT=2048, BW=20MHz, G=1/8, Frame Length=20ms, DownLink Modulation=64QAM-1/2, Uplink Modulation=16QAM-1/2, SNR=0dB.

Table IV. SIMULATION RESULTS FOR FFT=2048, BW=20MHz, G=1/8, FRAME LENGTH=20ms, DOWNLINK MODULATION=64QAM-1/2, UPLINK MODULATION=16QAM-1/2, SNR=30dB

<table>
<thead>
<tr>
<th>Noise Bandwidth (% sample rate)</th>
<th>Peak (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 (SNR=0 dB)</td>
<td>17.17</td>
</tr>
<tr>
<td>5</td>
<td>17.20</td>
</tr>
<tr>
<td>10</td>
<td>17.23</td>
</tr>
<tr>
<td>20</td>
<td>17.20</td>
</tr>
<tr>
<td>30</td>
<td>17.20</td>
</tr>
<tr>
<td>40</td>
<td>17.22</td>
</tr>
</tbody>
</table>

Figure 8 Peak (dB) versus Noise Bandwidth for Frame Length=20ms.

V. CONCLUSION

In this paper we investigated the impact of critical OFDMA parameters for different PSK/QPSK modulation schemes in the presence of high SNR values that are found both in Urban and Rural Environments. Simulations showed a significant degradation in BER as the Frame Length increases. Because of this degradation, critical OFDMA parameters playing an important role in the presence of high SNR values for reliable transmission for mobile users.

REFERENCES