PAPR Reduction in OFDM using Channel Coding in GNU Radio

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Abstract: The fundamental block of WiMAX (Worldwide Interoperability for Microwave Access) PHY layer is Orthogonal Frequency Division Multiplexing (OFDM). The main issue raised in OFDM is high Peak to Average Power Ratio (PAPR) due to multicarrier signal. This paper proposes architecture for PAPR reduction to improve network performance of WiMAX in urban areas where typically Non-Line of sight communications take place. The OFDM can be accomplished by using open source software, GNU Radio and a Software Defined Radio (SDR) hardware platform, USRP (Universal Software Radio Peripheral). In this paper, PAPR is calculated and compared for different modulation schemes, which are mainly used in OFDM. The obtained results proved that PAPR has reduced to 77.86% for 64-QAM (Quadrature Amplitude Modulation) and to 57.30% for QPSK (Quadrature Phase Shift Keying) using Channel Coding in GNU Radio.

Keywords: WiMAX, PAPR, OFDM, OFDMA, SDR, SER.

I. INTRODUCTION

In Software Defined Radio (SDR) [1], most signal processing works (Filtering, mixing, modulation, demodulation, amplify, etc.) in radio communications are done in software instead of hardware. The SDR is very pliable and allows multiple communication protocols which can dynamically execute on a same hardware. Significantly, signal processing is done in the general-purpose processor, rather than in special-purpose hardware. In general, SDR employs USRP (Universal Software Radio Peripheral) [2] as hardware setup and GNU radio [3] as software. WiMAX is a Broadband Wireless Technology (BWA) that defends fixed services (IEEE 802.16-2004 (Fixed WiMAX) [4]) and mobility services (IEEE 802.16e-2005 (Mobile WiMAX) [5]).

OFDM is a digital modulation method, in which a wideband signal is split into several narrowband channels at various frequencies. The primary advantage of OFDM over single-carrier schemes [6] is its ability to deal with severe channel conditions without complex equalization filters, because in OFDM, many slowly modulated narrowband signals are used than one rapidly modulated wideband signal. This multicarrier modulation nature of OFDM makes expedient in new wireless technologies (Wi-Fi, LTE, WiMAX, etc.) in order to reduce multipath fading and Inter-Carrier & Inter-Symbol Interference (ICI and ISI) [7]. The Orthogonal FrequencyDivision Multiple Access (OFDMA) [8] is integrated with AMC techniques [9] in order to get better efficiency, throughput, and fairness. The basic idea of WiMAX to support AMC is, transmit as high data rate as possible when channel is good and transmit as low data rates when channel is poor, in order to avoid excessive dropped packets. Lower data rates are attained by using small constellation such as QPSK and low rate error-correcting codes such as rate ½ convolutional or Turbo codes. The higher

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data rates are attained by using large constellation such as 64-QAM and less robust error correcting codes such as ¾ convolutional, turbo, or LDPC (Low Density Parity Check) codes.

II. GNU RADIO COMPANION

GNU Radio is a free and open-source software development toolkit that caters signal processing blocks to implement Software Defined Radios (SDR). The USRP will digitize the incoming data from the air and passing it to the GNU Radio through the USB or Ethernet interface. GNU Radio will then further process (demodulating and filtering) the signal until the signal is translated to a stream of data or packet. In GNU Radio, all signal processing is acted through flow graphs, which consists of blocks. A block does transforming, decoding, filtering, adding signals, hardware access or many others. Data passes between blocks in various formats, complex or real integers, floats or basically any kind of data type user can define. Every flow graph needs at least one sink and source. In GNU Radio, signal processing blocks are written in C++ and they are connected by using Python. SWIG (Simplified Wrapper and Interface Generator) is used as an interface compiler between C++ and Python language. Required GNU Radio modules are imported with the from gnuradio import command [3]. A flow graph in a class is derived from gr.top_block. Blocks can be created by addressing functions such as gr.sig_source_f() and saves the return value to a variable. Blocks can be connected by calling self.connect() from within the flow graph class. OFDM modulator and demodulator exist in ofdm.py python file [3]. The OFDM modulator block is configured with various parameters such as FFT length, occupied tones, cyclic prefix length, modulation scheme selection (which is used to generate OFDM symbol), etc.

III. OFDM AND OFDMA

OFDM combines modulation and multiplexing. Multiplexing adverts to independent signals, those developed by different sources. Fig. 1 shows, multicarrier modulation splits the wideband high data rate R bps incoming data stream and with a passband bandwidth B into L narrowband subsystems, each with rate R/L and passband bandwidth B/L, each of which is then transmitted over a different orthogonal-frequency subchannel.

The data rate of WiMAX is given by

\[ R = \frac{B.L_c \log_2(M)}{L(1+G)} \]  \hspace{1cm} (1)

If 16-QAM is used as modulation scheme in OFDM-WiMAX PHY layer, the data rate is as follows,

\[ R = \frac{10^7 MHz \times 768 \log_2(16)}{1024 \times 1.125} = 24 Mbps \]  \hspace{1cm} (2)

In words, each \( L_d \) data-carrying subcarriers of bandwidth B/L carries \( \log_2 M \) bits of data. An additional overhead penalty of \((1+G)\) must be paid for the cyclic prefix, since it consists of redundant information and sacrifices the transmission of actual data symbols.
PAPR Problem can be defined as when high peak signals transmitted through a nonlinear device such as a high-power amplifier (HPA), generates out-of-band energy (spectral regret) and in-band distortion (Constellation tilting and scattering) [9]. For a signal \( x(t) \), the peak to average power ratio is defined as [10],

\[
PAPR = \frac{\max[x(t) \cdot x^\ast(t)]}{E[x(t) \cdot x^\ast(t)]}
\]  

(3)

Where \( x^\ast(t) \) represents the conjugate operator.

Expressing in decibels, \( PAPR_{dB} = 10 \log_{10}(PAPR) \)  

(4)

Maximum expected PAPR from an OFDM waveform.

Let the transmit signal, \( x(t) = \sum_{0}^{L-1} a_i e^{j\frac{2\pi}{L} i \cdot t} \)  

(5)

For simplicity, let us assume that \( a_i = 1 \) for all the subcarriers. In that scenario, the peak value of the signal is [10].

\[
\max[x(t) \cdot x^\ast(t)] = \max \left[ \sum_{0}^{L-1} a_i e^{j\frac{2\pi}{L} i \cdot t} \sum_{0}^{L-1} a^\ast_i e^{-j\frac{2\pi}{L} i \cdot t} \right]
\]

\[
= \max \left[ a_i a^\ast_i \sum_{0}^{L-1} e^{j\frac{2\pi}{L} i \cdot t} \sum_{0}^{L-1} e^{-j\frac{2\pi}{L} i \cdot t} \right] = L^2
\]  

(6)

The mean square value of the signal is [10],

\[
E[x(t) \cdot x^\ast(t)] = E \left[ \sum_{0}^{L-1} a_i e^{j\frac{2\pi}{L} i \cdot t} \sum_{0}^{L-1} a^\ast_i e^{-j\frac{2\pi}{L} i \cdot t} \right]
\]

\[
= E \left[ a_i a^\ast_i \sum_{0}^{L-1} e^{j\frac{2\pi}{L} i \cdot t} \sum_{0}^{L-1} e^{-j\frac{2\pi}{L} i \cdot t} \right] = L
\]  

(7)

Given so, the peak to average power ratio for an OFDM with \( L \) subcarriers and all subcarriers are given the same modulation is,

\[
PAPR = \frac{L^2}{L} = L
\]

(8)

It is reasonably visceral that the above value represents the maximum value of PAPR (when all subcarriers are equally modulated and ordinate in phase and the peak value attains the maximum).

OFDMA is a multi-user version of the OFDM digital modulation scheme [8]. Multiple accesses are accomplished in OFDMA by allotting subsets of subcarriers to individual users as shown in Fig. 2. Every OFDMA subcarrier symbol has four types of subcarriers. Data subcarriers are used for data, Pilot subcarriers are used for channel estimation, DC subcarriers together with Guard subcarriers used for guard bands are shown in fig. 2.

![Fig. 2. OFDMA symbol in Frequency domain representation.](image-url)
The Mobile WiMAX (IEEE 802.16e-2005 [5]) is based on Scalable Orthogonal Frequency Division Multiple Access (SOFDMA) [11]. The SOFDMA advertises the capability of opting the number of subcarriers according to the available bandwidth. Fig. 3 shows the WiMAX building blocks have OFDMA symbol-level, bit-level, and digital intermediate frequency (IF) processing blocks. The baseband signals generated by GNU Radio must be extrapolated in the USRP in order to achieve the target bandwidth and then be up converted to the desired RF band in TX (Transmitter). The radio link is a rapidly varying link, often enduring from great interference. Channel coding is used to preclude and to adjust the transmission errors of wireless systems, must have a very good performance in order to preserve high data rates. The 802.16 channel coding chain is framed of three steps: Randomizer, Forward Error Correction (FEC) and Interleaving.

**A. Randomizer**

Data randomization is accomplished on each uplink and downlink burst of data. If the quantity of data to transmit does not equip exactly the quantity of data allocated, ploding of 0xFF is added to the end of the transmission block. The Pseudo-Random Binary Sequence (PRBS) generator is employed for randomization.

![Fig. 3. Scalable OFDMA-WiMAX PHY layer [11].](image)

**B. FEC encodings**

- (Tail-biting) Convolutional Code (CC)- This code is mandatory according to the 802.16 standard [9]. The Zero-Tailing Convolutional Code (ZT CC) is mandatory for WiMAX.
- Convolutional Turbo Coding (CTC) - According to the 802.16 standards, this code is optional. Yet, the CTC mandatory, according to Mobile WiMAX profiles.
- Block Turbo Coding (BTC) is optional.
- Low Density Parity Check (LDPC) codes are optional.
C. Interleaving
Interleaving is used to defend the transmission against long successions of sequential errors, which are very difficult to adjust. The interleaving is attained in two steps:
1. Disperse the coded bits over subcarriers. A first permutation guarantees that adjacent coded bits are mapped on to nonadjacent subcarriers.
2. The second permutation guarantees that adjacent coded bits are mapped alternately on to more or less significant bits of the constellation, thus averting long runs of bits of low reliability.

D. Repetition
Repetition was suggested by the 16e amendment for OFDMA PHY. It is used to raise the signal margin boost over the modulation and FEC mechanisms.

IV. SIMULATION RESULTS
Required Scalable OFDMA-WiMAX specifications (Table. 1) are implemented in GNU Radio. OFDM is implemented for 64-QAM modulation scheme without Channel Coding as in Fig. 4 and for 64-QAM modulation scheme with Channel Coding as in Fig. 6. The OFDM modulator converts the given data to packets. The Multiply Const block behaves as an amplifier, which can be controlled by the multi_const variable. The Channel Model block simulates a wireless channel. It can be configured by various parameters such as noise voltage, frequency offset, etc. The Throttle block is added to reduce the burden on CPU. The FFT sink is a graphical sink that plots the output signal in frequency domain. Peak to Average Power Ratio (PAPR) in OFDM is compared as follows,
\[
PAPR = \frac{\text{Peak Power}}{\text{Average Power}} = \left( \frac{\text{Modulated signal Amplitude}}{\text{Average signal Amplitude}} \right)^2
\]
(9)
Table. 2 shows the values for two modulation schemes (64-QAM, QPSK) and PAPR has reduced to 77.86% for 64-QAM and to 57.30% for QPSK using channel coding. PAPR reduction has improved greatly as modulation size increases. As reducing the average power of signal, Signal to Noise Ratio (SNR) at receiver will reduce, which degrades the performance. So, in this paper, instead of reducing the peak power, average power is increased for PAPR reduction.

<table>
<thead>
<tr>
<th>Channel Bandwidth (MHz)</th>
<th>1.25</th>
<th>5</th>
<th>10</th>
<th>20</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sampling Frequency (MHz)</td>
<td>1.4</td>
<td>5.6</td>
<td>11.2</td>
<td>22.4</td>
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<tr>
<td>FFT Size (N)</td>
<td>128</td>
<td>512</td>
<td>1024</td>
<td>2048</td>
</tr>
<tr>
<td>No of used Subcarriers</td>
<td>72</td>
<td>360</td>
<td>720</td>
<td>1440</td>
</tr>
<tr>
<td>No of Pilot carriers</td>
<td>12</td>
<td>60</td>
<td>120</td>
<td>240</td>
</tr>
<tr>
<td>No of null guard band subcarriers</td>
<td>44</td>
<td>92</td>
<td>184</td>
<td>368</td>
</tr>
<tr>
<td>No of sub channels</td>
<td>2</td>
<td>8</td>
<td>16</td>
<td>32</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Modulation scheme</th>
<th>Channel coding</th>
<th>Original signal Amplitude (dB)</th>
<th>Average signal Amplitude (dB)</th>
<th>PAPR</th>
</tr>
</thead>
<tbody>
<tr>
<td>64-QAM NO</td>
<td>44</td>
<td>9</td>
<td>23.90</td>
<td></td>
</tr>
<tr>
<td>QPSK NO</td>
<td>44</td>
<td>5</td>
<td>77.44</td>
<td></td>
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<tr>
<td>64-QPSK YES</td>
<td>46</td>
<td>20</td>
<td>5.29</td>
<td></td>
</tr>
<tr>
<td>QPSK YES</td>
<td>46</td>
<td>8</td>
<td>33.06</td>
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</tbody>
</table>

V. CONCLUSION
The Scalable OFDMA WiMAX PHY layer is implemented in GNU Radio for Software Defined Radio. The results show that OFDM with Channel Coding has good PAPR reduction than OFDM without Channel Coding. Convolutional codes not only provide error correction capability but also achieve PAPR reduction when used in OFDM systems. As modulation size (M) increases data rate (R) increases, SNR increases, PAPR reduction increases and SER (Symbol Error Rate) also increases which is not desirable.
Fig. 4. GNU Radio schematic for the implementation of OFDM for 64-QAM modulation without Channel Coding.

Fig. 5. OFDM Average signal for 64-QAM modulation without Channel Coding.

Fig. 6. GNU Radio schematic for the Implementation of OFDM for 64-QAM modulation with Channel Coding.
Therefore, there is a tradeoff between size of QAM modulation and SER. So, radio parameters such as modulation, power and FFT size used to be carefully chosen to achieve better performance of communication.

REFERENCES