Validating IEEE 802.16e Designs with the Mobile WiMAX MIMO Library

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Validating IEEE 802.16e Designs
With The Mobile WiMAX MIMO Library

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Abstract

The IEEE 802.16e standard, often referred to as mobile WiMAX, specifies air interfaces for broadband wireless access (BWA) systems. The standard is expected to energize the BWA industry and open many opportunities to deploy systems in applications that were previously cost-prohibitive. Mobile WiMAX uses roaming and handoff to enable laptop and mobile phones to operate.

High throughput is particularly important in the eyes of WiMAX service providers, because a selling point for both 3G and WiMAX is speed. Also, network capacity will have a major impact on operator economics.

The 802.16e mobile WiMAX standard was approved in December 2005, and Agilent EEsof EDA released the 802.16e Mobile WiMAX Wireless Library in January 2006 for use with Agilent’s Advanced Design System (ADS) EDA software. Currently, Agilent has also released the 802.16e Mobile WiMAX MIMO (multiple-input multiple-output) Wireless Library to help enable the emerging mobile WiMAX MIMO market to gear up for mobile wireless applications.

MIMO technology addresses some of these issues by extending high throughput and improving network capacity. Despite these benefits, cost and power consumption will continue to be a challenge for designers -- especially when they are trying to achieve optimal system performance. The ADS Mobile WiMAX MIMO Library enables system designers to validate their MIMO system within the confines of the latest spec of 802.16e-2005. For example, effects of channel environment on the packet error rate (PER) of the system are demonstrated.
Introduction

The IEEE 802.16e-2005 wireless MAN (metropolitan area network) OFDMA (Orthogonal Frequency Division Multiple Access) mode, or mobile WiMAX, is based on scalable OFDMA (S-OFDMA). S-OFDMA supports a wide range of bandwidth set to flexibly address the need for various spectrum allocation and usage model requirements.

The mobile WiMAX specification defines the MIMO option, which is a key feature in mobile WiMAX. Smart antenna technologies typically involve complex vector or matrix operations on signals due to multiple antennas. OFDMA allows smart antenna operations to be performed on vector-flat sub-carriers. Complex equalizers are not required to compensate for frequency selective fading. OFDMA, therefore, is very well-suited to support smart antenna technologies. In fact, MIMO-OFDM/OFDMA is envisioned as the foundation for next generation broadband communication systems (such as 802.20, 3G LTE, and so on).

The Mobile WiMax Library for Advanced Design System allows system designers to validate their MIMO system within the confine of the latest spec of 802.16e-2005. By analyzing simulation results from range of RF interference, PA back off, IQ mismatch, phase noise values using MIMO channel within the Mobile WiMax Library, designers can easily assess system performance based on error vector magnitude (EVM) and packet error rate (PER) results.

In this article, the next section introduces the MIMO and mobile WiMAX MIMO, followed by a section introducing ADS Mobile WiMAX MIMO solution. The final section introduces EVM and constellation measurements under DC offset, RF MIMO interference, IQ imbalance, phase noise, and PA dBC1. The PER on MIMO channel is also introduced here.

MIMO/OFDMA In Mobile WiMAX

The mobile WiMAX OFDMA PHY supports a frame-based transmission which includes DL and UL subframe. The mobile WiMAX MIMO transmitter and receiver in Agilent ADS are shown in Figure 1.
In the mobile WiMAX MIMO downlink subframe, the first two parts are preamble and a mandatory PUSC (partial usage of subchannels) zone, which transmits some control messages (such as FCH, DL-MAP and UL-MAP). The zone after the PUSC zone is STC (SM) zone whose permutation mode may be PUSC, FUSC or AMC. In this zone, transmit diversity (STC) or spatial multiplexing (SM) can be implemented. In order to enhance channel estimation and tracking in MIMO receiver, a midamble (a training sequence) may be present at the first symbol in the STC (SM) zone. The bit stream is distributed into the transmit antennas according to the following transmission format matrix (assuming two transmit antennas):

<table>
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| STC      | \[
|          | \begin{bmatrix}
|          | S_1 - (S_2)^* \\
|          | S_2 (S_1)^* \\
|          | \end{bmatrix}
| SM (MIMO)| \[
|          | \begin{bmatrix}
|          | S_1 \\
|          | S_2 \\
|          | \end{bmatrix}
|          | |

**Table 1: Transmission format matrix**

Assuming the MIMO system is with \( M \) transmit antennas and \( N \) receiver antennas, the STC zone is taken to perform FFT transformation, each received subcarrier is as follows:

\[
r = Hs + w
\]  

(1)

Where $H$ is the $M \times N$ channel matrix, $s=[s_1, s_2, \ldots, s_M]^T$ is the $M$-dimensional transmit signal vector, $w$ is the $N$-dimensional vector of zero-mean noise with the variance of $\sigma^2$. The channel matrix $H$ can be estimated by the pilots by the Wiener filtering.

The MIMO decoder can be divided into linear and non-linear decoding techniques. The simplest MIMO decoder is the zero-forcing (ZF) decoder which inverts the channel matrix:

$$\hat{s} = (H^*H)^{-1}H^*r$$  \hspace{1cm} (2)

However this ZF decoder introduces noise at lower SNR (signal noise ratio). A better decoder, MMSE (minimum mean squared error), is employed to minimize the Mean Square Error:

$$\hat{s} = (H^*H + \frac{M}{\rho} \mathbf{I})^{-1}H^*r$$  \hspace{1cm} (3)

Where $\rho$ represents the SNR at each receive antenna, $M$ is the number of transmit antenna. In ADS mobile WiMAX MIMO Wireless Library, both ZF and MMSE were implemented.

### Mobile WiMAX MIMO Transceiver

Top-level both downlink and uplink MIMO fully coded signal sources (support Matrix A and B in Table 1) are provided in EEsof mobile WiMAX MIMO Library. Figure 2 shows the downlink RF top level source.

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**Figure 2:** Top-level downlink RF MIMO source

When we push down into this model, the detailed structure is in Figure 3.

WMAN_M_DL_2Ant_Src is the top level downlink baseband MIMO source. N_Tones and QAM_ModExtOsc (Q1 and Q2) can be simulated as various RF impairments (such as gain/phase error due to IQ mismatch and phase noise and etc).

The detailed structure can be shown if users push down these top level both DL/UL sources. For DL source, the STC with two transmit antennas and SM with two transmit antennas were supported. For UL source, the SM with two transmit antennas and collaborative SM with two transmit antennas were supported. Figure 4 shows the detail baseband downlink MIMO source.
Top-level downlink and uplink MIMO receivers are also provided in this new library. *Figure 5* shows the top level RF downlink MIMO receiver.

![Top-level RF downlink MIMO receiver](image1)

*Figure 5: Top-level of downlink RF MIMO receiver*

The schematic of this downlink RF MIMO receiver is shown in *Figure 6*. Component WMAN_M_DL_MIMO_Ant2_Rx is the top-level baseband downlink MIMO receiver.

![Schematic of downlink RF MIMO receiver](image2)

*Figure 6: Schematic of downlink RF MIMO receiver*
These MIMO receivers include time and frequency synchronization, channel estimation, soft channel decoding, and so on. Figure 7 is the schematic of top-level downlink baseband MIMO receiver. Corresponding to STC/MIMO transmitter, the 2 x 1 MISO and 2 x 2 MIMO were supported for both DL and UL receivers.

![Figure 7: Schematic of downlink baseband MIMO receiver](image1)

Except for the DL/UL transceiver, the MIMO ITU channel model, by adding transmit antenna correlation factor, is also implemented in this new mobile WiMAX MIMO Library. Figure 8 shows how to create a 2 x 2 MIMO by using ITU channel.

![Figure 8: 2 x 2 MIMO channel model](image2)
In the mobile WiMAX MIMO Library, various transmit measurements (such as spectrum mask, constellation, EVM, spectral flatness, etc) and receiver measurements (such as PER on MIMO channel model, sensitivity measurement, adjacent channel rejection, and so on) are provided.

**Simulation Examples**

The test benches with DC offset, MIMO RF interference, IQ imbalance, phase noise, and PA nonlinear distortion are introduced first. The PER on MIMO channel model is introduced at last in this section.

For the first five test benches (DC offset, MIMO RF interference, IQ imbalance, phase noise, and PA nonlinear distortion), the constellation, EVM, and average EVM versus subcarriers are output. The parameters of the 2 x 2 MIMO systems for the first five test cases are as follows: bandwidth 10 MHz, frame duration 5 msec, Cylic prefix 1/8, PUSC STC zone, coding rate 16-QAM, CC 3/4 and FFT size 1024 points, transmit peak power of preamble is 10 dBm.

**DC Offset**

DC offset interference is a key issue in the zero-IF system. *Figure 9* is a schematic of the test bench.

![Figure 9: Schematic of a DC offset test bench](image)

PulseRF can simulate the DC offset in ADS. Both P1 and P2 (PulseRF) were added to I and Q branches. The peak power and frequency position of RF pulse can be set to parameters PeakPower and FCarrier in PulseRF, respectively. *Figure 10* shows constellation diagrams of various peak power of RF pulse. As the peak power of DC offset is increased, constellation error is also increased.
Figure 10: Constellation diagrams of a 16-QAM using various peak power of RF pulse (a) 0 dBm, (b) 5 dBm, (c) 10 dBm, and (d) 15 dBm

Figure 11 shows the EVM and average EVM versus subcarriers. The total EVM value is increased when the peak power is increased (EVM = -31.543 dB when peak power of DC offset is 15 dBm and EVM = -46.748 dB when peak power of DC offset is 0 dBm). From the curves of EVM versus subcarriers, the DC offset interference just affects some subcarriers near to the DC carriers. Please note the number of subcarriers is 840 in PUSC. The DC subcarrier index is 419.

Figure 11: EVM and EVM versus subcarriers using various peak power of DC offset

**MIMO RF Interference**

The MIMO RF interference was proposed by [3] as follows:

\[ V_{\text{out}_1} = V_{\text{in}_1} + \text{Isolation}_{1-2} \times V_{\text{in}_2} \]  \hspace{1cm} (4)

*Isolation*\(_{1-2}\) means the relative power level of the signal delivered on RF block 2 (antenna 2), \(V_{\text{in}_2}\), observed at the site of RF block 1 (antenna 1) as an additive noise contribution, with respect to the power level of the signal delivered on RF block 1, \(V_{\text{in}_1}\). *Figure 12* shows this MIMO RF interference test bench in mobile WiMAX MIMO Library.

![Figure 12: Schematic of MIMO RF interference test bench](image)

G2 means the *Isolation*\(_{1-2}\) in the schematic and the parameter. Gain can be set to the relative power level of the signal delivered on RF block 2 (antenna 2). G1 means the *Isolation*\(_{2-1}\) in the schematic and the parameter. Gain can be set to the relative power level of the signal delivered on RF block 1 (antenna 1). *Figure 13* shows constellation diagrams with various MIMO RF interferences. As the amount of RF interference is increased, constellation error is also increased.

![Figure 13: Constellation diagrams of a 16-QAM using various MIMO RF interference (a) -30 dB, (b) -25 dB, (c) -20 dB, and (d) -15 dB](image)
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Figure 14 shows the EVM and average EVM versus subcarriers. The total EVM value is increased when the RF interference is increased (EVM = -14.533 dB when RF interference is -15 dB and EVM = -29.228 dB when RF interference is -30 dB).

**Figure 14:** EVM and EVM versus subcarriers of a 16-QAM using various MIMO RF interference

**IQ Imbalance**

IQ mismatch can be characterized by the gain error $\varepsilon$ between I and Q branch, and the phase mismatch $\theta$. The model for the IQ mismatch is given by [4] as,

\[
\begin{align*}
\text{Re}\{V_{out}\} &= \text{Re}\{V_{in}\} \\
\text{Im}\{V_{out}\} &= (1 + \varepsilon)\{\text{Im}\{V_{in}\}\cos(\theta) - \text{Re}\{V_{in}\}\sin(\theta)\} \\
V_{out} &= \text{Re}\{V_{out}\} + i\times\text{Im}\{V_{out}\}
\end{align*}
\]  

(5)

with $V_{out}$ as the time domain signal with IQ mismatch. $\text{Re}\{\}$ denotes the real part, and $\text{Im}\{\}$ the imaginary part. Figure 15 shows the test bench for IQ imbalance.

**Figure 15:** Schematic of IQ imbalance test bench

The parameters GainImbalance and PhaseImbalance (see Figure 2 and QAM_ModExtOsc in Figure 3) in the top-level RF MIMO source can be set to the IQ imbalance. Figure 16 shows constellation diagrams with various IQ imbalances. In Figure 16, we can see that the constellation is not much affected by the gain error of less than 0.4 dB, and the phase error of less than 4 degrees.

**Figure 16:** Constellation diagrams of a 16-QAM using various IQ imbalance: (a) 0.1 dB of gain, 1’ of phase mismatch, (b) 0.2 dB of gain, 2’ of phase mismatch, (c) 0.3 dB of gain, 3’ of phase mismatch, and (d) 0.4 dB of gain, 4’ of phase mismatch

Figure 17 shows the EVM and average EVM versus subcarriers. The total EVM value is increased when the IQ imbalance is increased (EVM = -26.289 dB when 0.4 dB of gain, 4’ of phase mismatch, and EVM = -38.103 dB when 0.1 dB of gain, 1’ of phase mismatch).

**Figure 17:** EVM and EVM versus subcarriers of a 16-QAM using various IQ imbalance
**Phase Noise**

The phase noise will be specified with a pole-zero model that is given by [3] as,

$$PSD(f) = PSD(0) \frac{1 + (f/f_z)^2}{1 + (f/f_p)^2}$$

(6)

where $PSD(0)$ is -100 dBc/Hz, $f_z$ is zero frequency, and $f_p$ is pole frequency. In ADS, the N_Tones can simulate phase noise by setting its parameters.

The schematic of phase noise test bench is same as that of IQ imbalance (see Figure 15). Push down into the top level RF source; set the parameter RandomPhase=Yes. The PhaseNoiseData setting is active in N_Tones. The N_Tones will generate the LO as what the user wants the phase noise in the N_Tones (see Figure 3).

*Figure 18* shows constellation diagrams with various phase noise. The phase noise of -85 dBc at 100 KHz offset is enough to satisfy the constellation error.

*Figure 18*: Constellation diagrams of a 16-QAM using various phase noise: (a) -95 dBc@100 KHz, (b) -90 dBc@100 KHz, (c) -85 dBc@100 KHz, and (d) -80 dBc@100 KHz

*Figure 19* shows the EVM and average EVM versus subcarriers of various phase noise. EVM =-23.066 dB when phase noise of -80 dBc at 100 KHz offset, and EVM =-38.096 dB when phase noise of -95 dBc at 100 KHz offset.
Power Amplifier Nonlinear Distortion

The PA nonlinear distortion analysis is very important in the PA design. The parameter Gain compression type can be set to TOI, dBc1, TOI+dBc1, PSat+GCSat+TOI, PSat+GCSat+dBc1, PSat+GCSat+TOI+dBc1, and gain compression data points vs. input power. The schematic of power amplifier test bench is same as that of IQ imbalance (see Figure 15). The Gain compression type is set to dBc1 in the test bench. Figure 20 shows constellation diagrams with various PA 1 dB gain compression point.

Figure 19: EVM and EVM versus subcarriers of a 16-QAM using various phase noise

Figure 20: Constellation diagrams of a 16-QAM using PA dBc1: (a) 12 dB, (b) 10 dB, (c) 8 dB, and (d) 6 dB
Figure 21 shows the EVM and average EVM versus subcarriers of various 1 dB gain compression point. EVM = -15.813 dB when PA dBc1=6 dB and EVM = -22.239 dB when PA dBc1=12 dB.

PER On MIMO Channel

To evaluate the performance of Mobile WiMAX MIMO system in ADS, the open-loop DL 2 x 2 MIMO is simulated in uncorrelated ITU PB3 channels with correlated transmit antennas. The parameters of the 2 x 2 MIMO systems are as follows: bandwidth 10 MHz, frame duration 5 msec, Cyclic prefix 1/8, PUSC STC zone, coding rate QPSK, CC 1/2, 16-QAM, CC 1/2, 64-QAM, CC ½, and FFT Size 1024 points. The schematic is shown in Figure 22.

Midamble is inserted to get the channel estimation with 2-D MMSE estimator. The linear MMSE MIMO decoder is employed. The FER (frame error ratio) vs. Eb/No is shown in the Figure 23, where the three curves corresponding to Rate ID 0 (QPSK, 1/2), 2 (16-
QAM, 1/2) and 4 (64-QAM, 1/2) of the transmit antenna correlation factor of $\rho = 0.2$, respectively.

![Downlink BER and PER on 2x2 ITU fading channels](image)

**Figure 23: 2 x 2 MIMO PER performances**

**Conclusion**

This paper introduces Mobile WiMAX MIMO and its implementation in ADS. For mobile WiMAX MIMO transmit measurements, the EVM, EVM versus subcarrier, and constellation measurement were tested under DC offset interference, RF MIMO interference, IQ imbalance, phase noise, and power amplifier 1 dB gain compression point. For receiver measurement, the PER on MIMO channel was introduced. The simulation results with combined RF impairments (such as MIMO RF interference with PA 1 dB gain compression point, IQ imbalance, and phase noise) did not provided in this paper. It is easy to simulate EVM with combined RF impairments by using the above test benches.

**References**


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