WiSim – A Software Simulation Testbed for Mobile WiMAX

BASHARAT SHAH, Y.V.RAO, SONY ELDHOSE, RUPPY VARDARAJAN

Research and Development Group,
Larsen and Toubro Infotech Limited, Whitefield, Bangalore, India-66

Abstract:- Next generation wireless system designing has the wide array of choices for advanced signal processing algorithms and a variety of operating environments. The scope and complexity of the IEEE 802.16 standard creates challenges for designers of standard-compliant components. Model based design addresses these challenges by placing a system model at the center of the development process from requirements capture to implementation and testing. This paper describes a software based testbed (WiSim) which simulates WiMAX Radio Air Interface both at link level and system level.

The WiSim testbed is a tool to evaluate various design options and trade-offs in different system and environment scenarios. WiSim simulates both MAC layer and three PHY's layers of WiMAX (SC PHY, OFDM PHY, OFDMA) PHY) based on IEEE 802.16-e standard. The simulator supports all the optional features like MIMO, Block Turbo coding, Space Time coding, Convolutional Turbo coding as mentioned in the standards. So a fair performance evaluation can be done between the mandatory and optional features. System level simulation parameters like Cell layout, BS and SS antenna parameters and Fast HARQ are considered in the simulator. The simulator supports SUI fixed broadband wireless channel model, ITU channel model and 3GPP MIMO channel model and a user can modify any one of the channel model parameter.

As the Standard does not talk much about the receiver design, various receiver algorithms for PAPR reduction, Time and frequency synchronization, Carrier frequency offset and channel estimation are identified vis-à-vis to WiMAX and are implemented in Simulator

Key-Words: WiMAX, OFDM, OFDMA, Link and System level simulator, Receiver design

1. Introduction

The IEEE 802.16 family of standards specifies the air interface of fixed and mobile broadband wireless access (BWA) systems that support multimedia services. A WiMAX system is one based on technologies of this family, sponsored by an industry consortium called the WiMAX Forum. The standard has now been updated and extended to the 802.16e standard for mobile access. Mobile WiMAX utilizes roaming and handoff to enable laptop and mobile phones operation. The 802.16 standard defines the specifications related to the convergence sublayer (CS), medium access control (MAC) layer, and physical layer (PHY). Its PHY supports four physical modes: WirelessMAN-SC for any applicable frequencies between 10 and 66 GHz, Wireless-MAN-SCa for licensed frequencies below 11 GHz, WirelessMAN-OFDM for orthogonal frequency-division multiplexing, and Wireless-MAN-OFDMA.

The remainder of this paper is organized as follows: Section II gives an overview about the need for this work. Section III gives the detailed overview of design and simulation methodology. Section IV, describes the features of the simulator. Section V talks about the proposed receiver design for WiMAX. Finally conclusions are given in Section VI.

2. Need for a WiMAX Testbed

A wide range of advanced signal processing algorithms and system configurations are available for designing a future cellular communication network. IEEE 802.16e standard does not give a particular configuration of parameters to work with. In addition many parameters like MIMO, STC, SBC, and HARQ are kept as optional in the standard. So there is a need to evaluate the performance of the whole system with these optional parameters. The simulation testbed allows the evaluation of the design choices in systems based on IEEE 802.16e standard. Other variables such as the parameters of the channel, which are affected by environmental factors, are included in the simulations. The simulation testbed is envisioned to have the following capabilities:

i. A comprehensive method of algorithm evaluation:

The typical method of evaluating a new algorithm, by doing a localized simulation, does not provide accurate insights into the algorithm behavior in a real system. WiSim aims at providing an environment which models all facets of a real wireless system and provides a complete picture of system behavior with various algorithms. Various algorithms for PAPR reduction, Time and frequency synchronization, carrier frequency offset, channel estimation and equalization are identified vis-à-vis to WiMAX and are implemented in the Simulator.

ii. Algorithm trade-off issues:

The algorithmic choices for each block differ in the computational complexity and in the resulting performance. WiSim is in-tended to assist in the choice of an algorithm.

iii. Performance evaluation of optional parameters:

In WiMAX standard features like MIMO, Block Turbo coding (BTC), Space Time coding (STC), and Convolutional Turbo coding (CTC) are put under the heading of optional features. So a fair performance evaluation is required for these optional parameters vis-à-vis to mandatory features and different combination of these features.

iv. Performance evaluation of various Physical layers:

IEEE 802.16e supports various Physical layers (SC- PHY, OFDM -PHY, OFDMA-PHY) WiSim can simulate all of these Physical layers and provides a performance evaluation among different Physical layers.

3. WiSim Design and simulation Methodology

In this section, we describe our design and simulation methodology. The protocol stack and signal flow of WiSim is shown in figure 1.

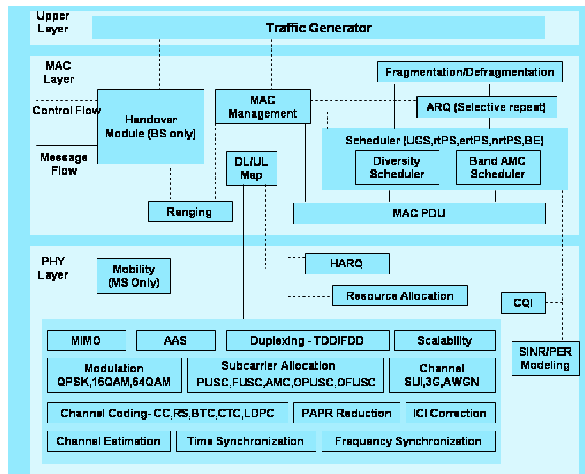

Figure1: Protocol stack and signal flow of Simulator

For Link layer simulations all the three Physical layers (SC, OFDM and OFDMA) of WiMAX are implemented in the simulator. Parameters pertaining to OFDM (IFFT size, cyclic prefix, number data and pilot subcarriers), Channel coding (Convolutional, Reed Solomon, BTC, CTC, STC, LDPC), Modulation (BPSK, QPSK, 16QAM, 64QAM) are supported by WiSim simulator.

System parameters like ARQ, Handover, MIMO, AAS, Beamforming, Bandwidth, Antenna parameters, Frame, Zone and Burst configuration (with symbol and frequency offsets), BSID are supported in the simulator. Parameters for system level simulations are tabulated in table 1:

Table1: System level parameters of WiSim

Parameter	Reference values *
Cellular layout	Hexagonal grid, 3-sector sites
Antenna horizontal pattern	70 deg (-3 dB) with 20 dB front-to- back ratio
Site to site distance	2800 m
Propagation model	L = 128.1 + 37.6 Log10(R)
Power allocated to WiMAX transmission	Max. 80 % of total cell power
Correlation between sectors	1.0
Correlation between sites	0.5
Carrier frequency	2000 MHz
BS antenna gain	14 dB
UE antenna gain	0 dB
UE noise figure	9 dB
Thermal noise density	-174 dBm/Hz
Max. # of retransmissions	3
Fast HARQ scheme	Chase combining or IR
BS total Tx power	Up to 44 dBm
Specific fast fading model	Jakes spectrum
WiMAX slot length	2 msec
MIMO configuration n x m	n x m n=1,2,3,4 m= 1,2,3,4
Channel width	5 MHz

* Reference values shown are default values and most of them are user defined in the WiSim simulator.

3.1 OFDM PHY

The IEEE 802.16 OFDM PHY is designed for both LOS and NLOS operations in bands below 11GHz. Channel Bandwidths vary from 1.25 MHz to 28 MHz. The OFDM based PHY uses 256 point FFT resulting in 256 subcarriers. There are three types of sub-carriers in OFDMA:

1) Data sub-carriers for data transmission.
2) Pilot sub-carriers for various estimation and synchronization purposes.
3) Null sub-carriers for no transmission at all, used for guard bands (left and right) and DC carriers.

3.2 OFDMA PHY

In OFDMA active sub-carriers are divided into subsets of sub-carriers called sub-channels. The sub-carriers forming one sub-channel may be, but not need to be, contiguous. Different ways of grouping sub-carriers into channels in 802.16 are called permutations. There are three main permutations:

i. **FUSC:** Full Usage of Sub-channels (DL only): Achieves best frequency diversity by spreading the sub-carriers over the entire band

ii. **PUSC:** Partial Usage of Sub-channels (UL and DL).Groups the sub-carriers into tiles to enable fractional frequency reuse scheme (FFRS).

iii. **AMC:** (or Band AMC): Adaptive Modulation and Coding (UL and DL).his permutation is also known as Adjacent Sub-carrier Permutation. It uses adjacent sub-carriers for each sub-channel for use with beam forming

Alternative permutations, such as TUSC (supporting both beam forming and OFDMA permutation) might be used as an option in the DL sub-frame.

Flow diagrams of Link layer simulations with SUI channel model is shown in figure 2.

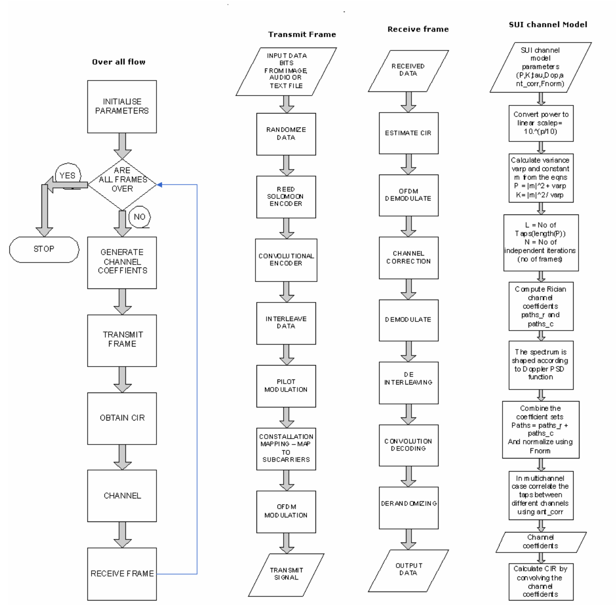

Figure2: Flow diagram of WiSim Simulator

4. Features of WiSim

The WiSim simulator offers the advantages of modularity, scalability and efficient simulation. The use of C and Java provides faster and more user friendly features in the simulator. Main features of WiSim are tabulated in table 2.

Table2: Features of WiSim

Modulation Formats:	BPSK, QPSK, 16QAM, 64 QAM.
Channel coding:	Reed Salomon Inner code and Convolutional Outer code, with code parameters modifiable by user, BTC, STC, CTC, LDPC
Operational Modes:	Downlink, Uplink
Duplxing:	FDD, TDD
Input Data:	Image, Audio, Text, Random Data, Test Vectors,
Cyclic prefix:	User defined
BS and SS Antenna Heights:	User Defined
Channel Models:	Stanford interim University (SUI) fixed broadband wireless channel model. ITU channel model. 3GPP MIMO channel model
Plotting:	Transmitted and Received Signal Constellation, Transmitted and Received Signals, Transmitted and Received Signal Eye diagram, Transmitted and Received Image, Audio and Text, Channel Frequency response, Bandwidth efficiency Plot, BER SER, FER plots, Channel Impulse response PSD of modulated signal, PSD of Tx and Rx signals, CCDF, Frequency response of Received signal
Zone types:	PUSC, FUSC, AMC, OFUSC, TUSC-1, TUSC-2
Burst Creation:	User made with user defined symbol and frequency offsets
HARQ:	Chase combining, Incremental redundancy
Transceiver Algorithms:	PAPR reduction, Channel estimation and equalization, Course synchronization, Fine synchronization, ICI correction
Display parameters	Throughput, sampling factor, sampling frequency, subcarrier spacing, OFDM symbol duration. Number of frames transmitted, Burst time, Data length, BSID, RATE ID, DIUC, Transmitter Power, Modulation, Inner-coding rate, Outer-coding Rate, RSSI, CINR

4.1. Channel Modeling

Channel model plays an important role in performance evaluation of any wireless communication system. Any channel model is heavily dependent on the radio architecture and suffers from several impairments. The wireless channel is characterized by: Path Loss, Shadowing, Multipath Delay Spread, Fading Characteristics, Doppler Spread, Co-channel and adjacent channel interference. All the channel impairments are random and only a statistical characterization of the parameters is possible. All the channel parameters are dependent on several factors such as terrain, topography, density of vegetation, antenna height, wind speed, beamwidth, time of the year and other factors.

In WiSim three different channel models are implemented.

i. Stanford interim University (SUI) fixed broadband wireless channel model.
ii. ITU channel model
iii. 3GPP MIMO channel model

A user can modify any one of the channel model parameter e.g. in SUI channel model in addition to 6 different channel scenarios (SUI 1-6) , user can create a new scenario based on the actual measured channel parameters like delay, average fade duration, Doppler shift, Rician factor ,power and so on.

5. Receiver Design

WiMAX Standard does not talk much about the receiver design. As WiMAX is based on OFDM/OFDMA, the problems associated with these needs to be addressed at the receiver side for efficient performance of the system. Various algorithms for PAPR reduction, Time and frequency synchronization, Carrier frequency offset and channel estimation are identified vis-à-vis to WiMAX and are implemented in Simulator.

Figure 2 shows the WiMAX receiver design for WiSim.

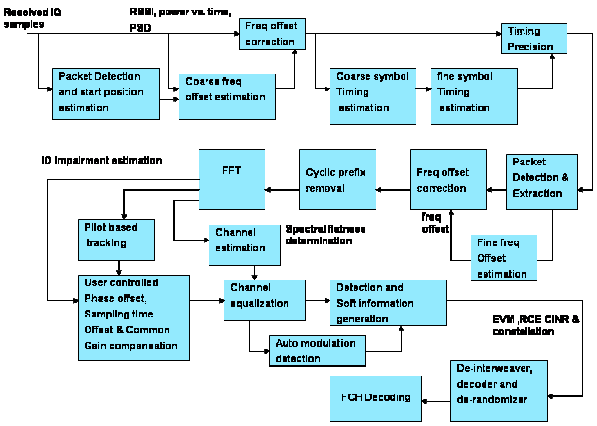

Figure3: WiMAX receiver design for WiSim

In addition to conventional OFDM receiver design our WiMAX receiver, performs various other operations: It finds the RF burst and packet edge for the bursts; estimate and correct the coarse frequency offset; estimate and perform coarse and fine symbol time synchronization; estimate packet end position, and extract useful packet information; perform fine frequency-offset estimation and correction of remaining frequency offset; estimate the channel-frequency response (CFR) and correct symbol rotations due to common and carrier dependent phase offset; employ frequency domain equalization using the CFR; detect the symbols and obtain soft symbol values to be used by the channel decoder; employ de-interleaver/decoder/ derandomizer; decode the FCH field and check the CRC.

5.1 PAPR reduction

In WiMAX an OFDM signal consists of number of independently modulated subcarriers which can give a large Peak to Average power ratio (PAPR) when added up coherently. Large PAPR puts a stringent requirement on the power amplifier and reduces the efficiency in the sense that a higher input backoff factor is needed before the peaks in the signal experiences significant distortion due to power amplifier non linearity. It also increases the complexity of ADC and DAC's. To reduce PAPR several techniques have been proposed. In this paper we have investigated these PAPR reduction algorithms and applied following to the simulator.

I. Clipping
II. Peak Windowing
III. Active constellation Extension (ACE)
IV. Metric-based symbol pre-distortion (MBSP)

These algorithms do not alter the speciation and are inline with them. The simulator can perform simulations with and without these algorithms to evaluate the performance of the WiMAX system.

5.1.1 Time and frequency synchronization

Synchronization is very critical in multicarrier systems. Impact of synchronization errors results in two types of effects: Time domain effects and Frequency domain effects. Time domain effects gives rise to packet detection errors and packet loss. Also incorrect symbol window leads to ISI. Frequency domain effects gives rise to incorrect packet start, rotation of signal constellation and inter carrier interference.

In WiMAX training sequences are inserted within the data symbols to help synchronization and channel estimation. The downlink subframe begins with two OFDM symbols used for synchronization and channel estimation at the subscriber station. These two symbols together represent the preamble of the DL subframe and are referred to as the "long preamble." The uplink subframe begins with one OFDM symbol that is used at the base station for synchronization to the individual SS. This single uplink symbol is referred to as the "short preamble." The first symbol in the long preamble is composed of every 4th OFDM carrier (50 out of 200 total). Therefore, the time-domain signal has four repeated parts. While the first symbol in the long preamble is useful for coarse signal acquisition, it is not sufficient for detailed channel measurement and correction. Therefore in the downlink subframe, the first symbol is followed by another of the same length, containing alternate active carriers. The

second symbol in time domain has two repeated parts.
In our simulator we addressed both time synchronization and frequency synchronization. In time synchronization we addressed Course as well as fine synchronization. Algorithms like 'Delay and Correlate' and Maximum likelihood estimation are used for time and frequency synchronization.

5.1.2 Channel estimation and Equalization

In order to undo the effects of the channel, channel estimation and equalization should be done at the receiver. With respect to WiMAX estimation can be performed in two possible ways using the pilot subcarriers as defined in standard. The first method inserts pilot tones in all of the sub-carriers of the OFDM symbols with a specific period. The second method inserts pilot tones in each of the OFDM symbols. These are known as block type and comb type channel estimation respectively.
The structure of OFDM signaling permits a channel estimator that uses both on time as well as frequency correlation.
The channel estimation for our simulator is based on

I. Least Square estimation
II. Minimum Mean Square error estimates.

For OFDMA PHY of WiMAX we used a two-dimensional channel estimator. After estimating the channel, the received signal needs to be equalized. If the cyclic prefix is longer than the maximum delay spread of the channel, we can model the effect of the channel as a complex multiplication in the frequency domain. The equalization thus simplifies to a complex division of the received signal by the estimated channel. WiSim also supports time domain channel equalizer which is based on shortening of channel impulse response (CIR).

5.1.3 Frequency offset

OFDM systems are very sensitive to frequency errors. These frequency errors are caused by the differences in the transmitter and receiver frequencies and by the Doppler shift caused by the relative motion between transmitter and receiver. As a result orthogonality between subcarriers is lost which results in carrier frequency offset. At the receiver side measures should be taken to correct these errors. Following algorithms were implemented in our simulator:

i. Self cancellation
ii. Maximum likelihood based CFO estimation and cancellation
iii. Kalman filter based CFO estimation and cancellation

Simulations can be run using any of these algorithms and the tradeoff between these algorithms in terms of BER can be evaluated in conjunction with other receiver algorithms.

5.2 WiSim Snapshots

This section shows some of the snapshots of the WiSim simulator. Figure 4 shows snapshot of main panel of OFDM PHY.

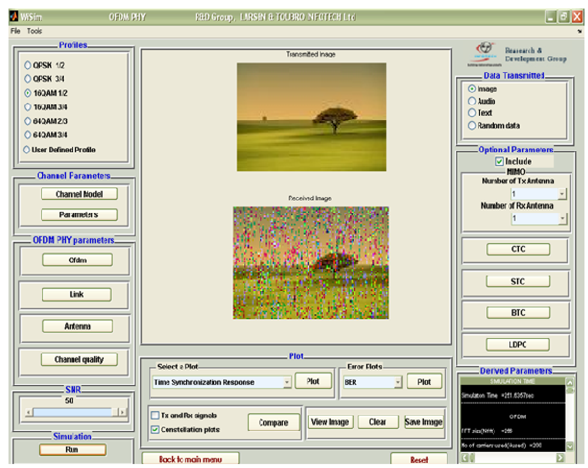

Figure4: Snapshot of OFDM PHY of WiSim Simulator

Using the OFDMA PHY of WiSim, the user can define:

i. The number of symbols in the OFDMA frame (48 by default)
ii. The number of overhead symbols in the Downlink
iii. The number of overhead symbols in the Uplink
iv. The UL/DL duration ratio (1:1, 12:25, 9:28…)
v. The number of symbols included in the Time Transition Gap (TTG)

Based upon these inputs, the simulator calculates the number of data symbols used in DL and UL. If crossed with the modulation and the number of OFDMA data sub-carriers used per frame, WiSim can calculate the corresponding throughput in DL and UL .Figure 5 shows frame configuration panels of the simulator and Figure 6 shows plotting panel with user defined Burst configuration of the simulator. WiSim also has separate panels for system, zone and Burst configuration.

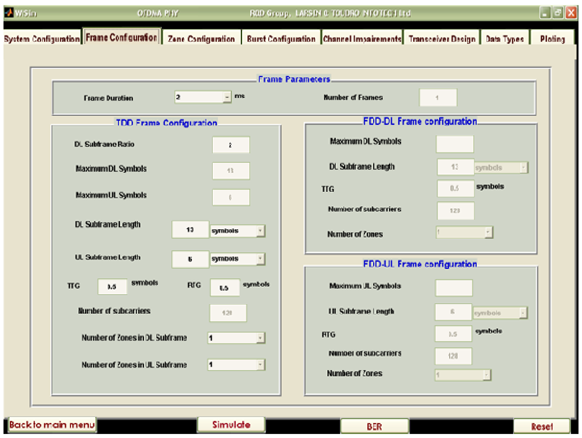

Figure 5: Snapshot of frame configuration panel for OFDMA PHY of WiSim Simulator

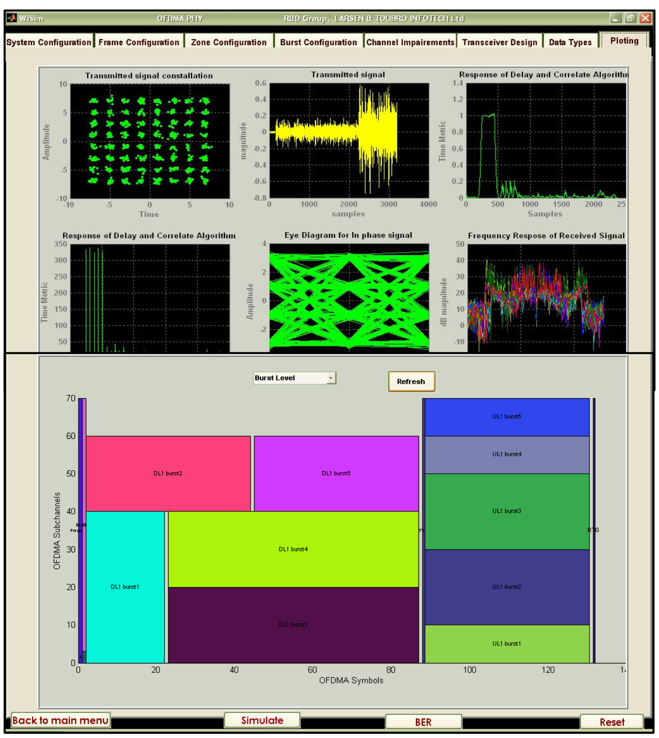

Figure 6: Snapshot of plotting panel and Burst configuration for OFDMA PHY of WiSim Simulator

Figure 7 shows Channel selection sub panel of the simulator.

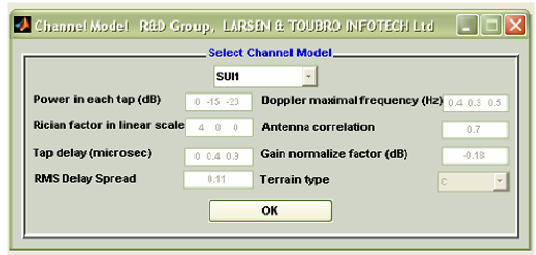

Figure 7: Snapshot of SUI channel selection sub panel

Figure 8 Transceiver design panel of the simulator.

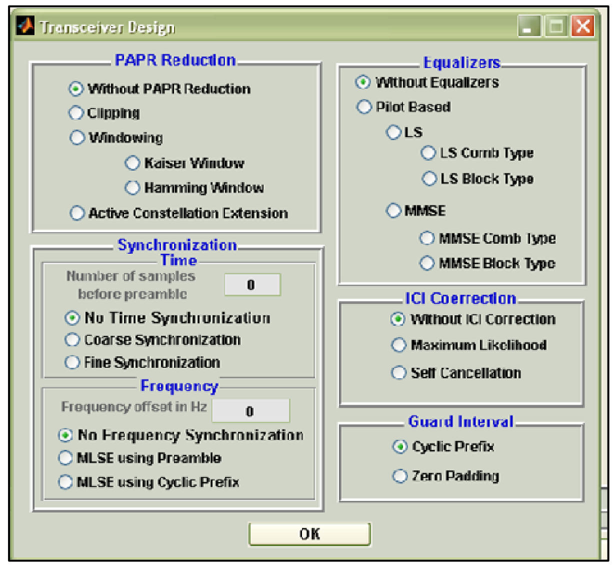

Figure 8: Snapshot of plotting panel for OFDMA PHY of WiSim Simulator

8. Conclusions

In this paper we have presented WiMAX simulator which can be used to evaluate the performance both at link and system level. Various Receiver algorithms have been added to the simulator so as to get fair idea about the whole WiMAX system .Performance in terms of BER, SER, FER, Complexity and throughput under appropriate channel models can be evaluated by the simulator. Performance of all the optional features given in the standards can be evaluated using WiSim. At system level the simulator can evaluate the performance by considering MIMO, HARQ and Handover. Various Test vectors are also incorporated in

WiSim Simulator so that the system can be tested thoroughly.

References

[1] Air Interface for Fixed Broadband Wireless Access Systems, IEEE Std 802.16 2004, October 2004.

[2] Air Interface for Fixed and Mobile Broadband Wireless Access Systems, IEEE P802.16e/D12, February, 2005

[3] Hassan Yagoobi, .Scalable OFDMA Physical Layer in IEEE 802.16 WirelessMAN, Intel Technology Journal, Vol 08, August 2004

[4] WiMAX End-to-End Network Systems Architecture - Stage 2: Architecture Tenets, Reference Model and Reference Points, WiMAX Forum, December, 2005

[5] Mobile WiMAX. Part II: Competitive Analysis, WiMAX Forum, February, 2006

[6] A. Ghosh et al., "Broadband Wireless Access with WiMAX/ 802.16: Current Performance Benchmarks and Future Potential," IEEE Communication Magazine., Feb. 2005, pp. 129–36.

[7] I. Koffman and V. Roman, "Broadband Wireless Access Solutions based on OFDM Access in IEEE 802.16," IEEE Communication Magazine., Apr. 2002, pp. 96–103.

[8] B. S. Krongold and D. L. Jones, "PAR Reduction in OFDM via Active Constellation Extension," *IEEE Transactions on Broadcasting*, vol. 3, pp. 258-268, September 2003.

[9] *IEEE C802.16d-04_47*, applying scalability for the OFDMA PHY layer.

[10] *C802.16REVd-04_50r3*, OFDMA PHY enhancements for better mobility performance.

[11] *IEEE C802.16d-04/90*, AAS enhancements for OFDMA PHY

[12] *IEEE 802.16d-04/65*, Enhancing MIMO features for OFDMA PHY layer

[13] *IEEE C802.16e-04_72r2*, STC Enhancements for optional FUSC and AMC zones for OFDMA PHY layer