Implementation of WIMAX IEEE 802.16e Baseband Transceiver on Multi-Core Software Defined Radio Platform

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***Abstract*—Advancements in broadband and mobile communication have provided many privileges to its subscribers, such as high-speed data connectivity and good quality voice and video application services for economical rates. WIMAX is an eminent technology that provides broadband and IP connectivity to "last mile" scenarios. It offers both line of sight and non-line of sight wireless communication. Orthogonal frequency division multiple access, which uses the concept of cyclic prefix to add additional bits at the transmitter end, is used by WIMAX on its physical layer. The signal is transmitted through the channel and then received at the receiver end. Afterwards, the receiver removes these additional bits in order to minimize the inter symbol interference, improve the bit error rate, and reduce the power spectrum. In our research work, we investigated the physical layer performance on the basis of bit error rate and of signal-to-noise ratio. These parameters are discussed in four different models. This paper seeks a new approach to the adaptation of the WIMAX IEEE802.16e baseband for the SFF SDR Development Platform. The original implementation of the signal processing phase is proposed in order to dynamically support incoming signals of the WIMAX baseband.**

***Index Terms*—WIMAX, SFF SDR, OFDM, RS, Coding, AWGN, FFT, IFFT.**

I. INTRODUCTION

Some decades ago, we were purely dependent on analog system. Both the sources and transmission system were on analog format but the advancement of technology made it possible to transmit data in digital form. Along with those, the computer was getting faster to the fastest, the data payload capacity and transmission rate increased from kilobit to megabit and megabit to gigabit. From wire to wireless concept emerged and after researching and investing so much money, engineers became successful to invent wireless transmitter to transmit data. Applications like voice, Internet access [1], instant messaging, SMS, paging, file transferring, video conferencing, gaming and entertainment etc became a part of life. Cellular phone systems, WLAN, wide-area wireless data systems, ad-hoc wireless networks and satellite systems etc are wireless communication. All emerged based on wireless technology to provide higher throughput, immense mobility, longer range, robust backbone to thereat. The vision extended a bit more by the engineers to provide smooth transmission of multimedia anywhere on the globe through variety of applications and devices leading a new concept of wireless communication which is cheap and flexible to implement even in odd environment. This is a fact that, Wireless Broadband Access (WBA) via DSL, T1-line or cable infrastructure is not available especially in rural areas. The DSL can covers only up to near about 18,000 feet (3 miles), this means that many urban, suburban, and rural areas may not served [2]. The Wi-Fi standard broadband connection may solve this problem a bit but not possible in everywhere due to coverage limitations. But the Metropolitan-Area Wireless standard which is called WIMAX can solve these limitations. The wireless broadband connection is much easier to deploy, have long range of coverage, easier to access and more Performance Evaluation of IEEE 802.16e (Mobile WIMAX) in OFDM Physical Layer flexible. This connectivity is really important for developing countries and IEEE 802.16 family helps to solve the last mile connectivity problems with BWA connectivity. IEEE 802.16e can operate in both Line-Of-Sight (LOS) and Non-Line-Of-Sight (NLOS) environments. In NLOS, the PHY specification is extended to 211 GHz frequency band which aim is to fight with fading and multipath propagation [3, 4]. The OFDM physical layer based IEEE 802.16 standard is almost identical to European Telecommunications Standard Institute's (ETSI) High performance Metropolitan Area Network (HiperMAN) as they cooperate with each other [5]. This paper is all about WIMAX OFDM PHY layer performance where we analyzed the results using the SFF SDR Development Platform with different modulation techniques. SDR allows the coexistence of different independent standards, protocols, and services. This signal processing approach is broadly spreading given that reprogramming and reconfiguring of fixed and mobile devices is of great importance. Due to the availability of SDR in the device architecture, a user can update and replace necessary services without changing the hardware [6].

II. WIMAX IEEE 802.16 E

WIMAX IEEE 802.16e was an amendment of 802.16d standard which finished in 2005 and known as 802.16e-2005. Its main aim is mobility including large range of coverage. Sometimes it is called mobile WIMAX. This standard is a technical updates of fixed WIMAX which has robust support of mobile broadband. Mobile WIMAX was built on

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Orthogonal Frequency Division Multiple Access (OFDMA). It mentioned that, both standards (802.16d-2004 and 802.16e-2005) support the 256-FFT size. The OFDMA system divides signals into sub-channels to enlarge resistance to multipath interference. For instance, if a 30 MHz channel is divided into 1000 sub-channels, each user would concede some sub-channels which are based on distance[3].

III. SFF SDR DEVELOPMENT PLATFORMS

The SFF SDR Development Platform is shown in Figure 1 consists of three distinct hardware modules that offer flexible development capabilities: the digital processing, data conversion, and RF module. The digital processing module uses a Virtex-4 FPGA and a DM6446 SoC to offer developers the necessary performance for implementing custom IP and acceleration functions with varying requirements from one protocol to another supported on the same hardware. The data conversion module is equipped with dual-channel analog-to-digital and digital-to-analog converters. The RF module covers a variety of frequency ranges in transmission and reception, allowing it to support a wide range of applications [7].

Fig .1. SFF SDR Development Platform[7]

A. *System performance analysis and optimization target*

MathWorks and Texas Instruments (TI), the two companies responsible for the development of Matlab/Simulink, are currently working on the development of a DSP development tool that users can use through Simulink. The object modules, designed to meet their own needs, the programming system, which is implemented through Real- Time Workshop, and the S-function with the TLC (Target Language Compiler) Function of the system design, when completed, can be directly converted to the most commonly used DSP programming language. The DSP, in conjunction with the TI software, Code Composer Studio, is completed in combination with the DSP hardware. Thus, through this development tool, users can work together to complete the design and simulation on the Simulink; however, it cannot provide the convenience of design that could increase the set count on the efficiency.

B. *A-1 System integration and implementation of workflow*

In the development and testing of IEEE 802.16e Wireless MAN-OFDM PHY, the specifications of communication Transfers have varying systems, which are based on our needs under Simulink mentioned in the proposed system for WIMAX. IEEE 802.16e for our study, we used the standard communication system box with a map provided by Matlab, which contains the following: Internal Communications Blockset, Signal processing Blockset, and Simulink Blockset. These correspond to our use of the hardware development platform for SFF SDR DP Blockset. The overall WIMAX PHY system construction is opened in the Simulink interface and Matlab is used to communicate the internal functions of RTW and TLC. We intend to build a finished system into a module, in accordance with the code of each block. Through this, we can perform the compilation and completion that will be automatically compiled in Matlab CCS connecting knot. The CCS establishes a corresponding module under the file name "Project." We then correct the generated C code and conduct compilation, debugging, and analysis. We then download our work into to the DSP. The overall system workflow is shown in Figure 2. The figure shows the system built based on the Simulink-established IEEE 802.16e Wireless MAN-OFDM PHY standard modules. The first step is the configuration by Simulink of the parameters interface and development platform into the conduct of the connecting node configuration. Information will be set to leave the bulk form of a fixed number of patterns, and the RTW system development module is set to be transferred and replaced by C language. Meanwhile, the TLC file option SDR development of modules and the set up Simulink system development are scheduled for DSP link module by an external module through the executive. Configuration of the IEEE 802.16e Wireless MAN-OFDM PHY may be achieved through the DSP Options Block Simulink to develop interfaces connecting node, development platform, and CCS. The use of the DSP Options Block and the Compiler Options allow us to optimize the system and the executive profit use. Moreover, future compiler optimization can be conducted through the Block. In the SFF SDR Development Platform of the DSP configuration, three kinds of memory are used: L1DRAM (8 KB), L2RAM (64 KB), and SDRAM (8 MB). The L1DRAM and L2RAM are used for the internal memory, while the SDRAM is used for the external memory. Due to the retention of internal memory, the speeds become quicker; thus, if information is to be placed in the internal memory in the system as a whole, the speeds and the executive would enhance performance Thus, the CMD File Generator Block for Development Platform can be conducted into the memory settings [7].

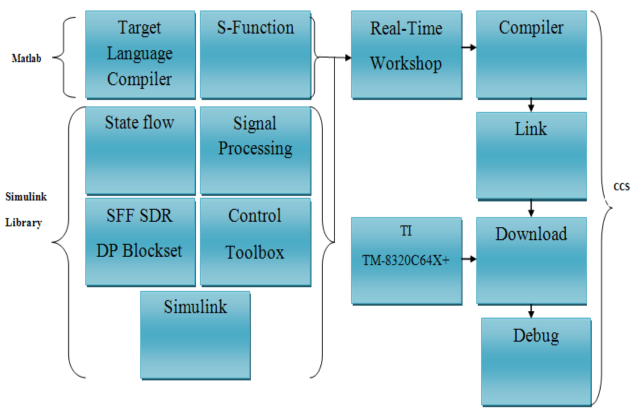

Fig .2. Schematic diagram of the system workflow actions [7]

C. *A-2 TLC and RTW.*

Target Language Compiler (TLC) is a Matlab program that uses syntax. Developers using the RTW tool can use the TLC to create self-designed C syntax language code by adding to the executive after the RTW-generated C language code or design. The use the S-function in the input and output of the set can design its own system for C programming and create Simulink objects in the box to use; however, RTW is only responsible for producing the C language program yards. It will not check the correct use of grammar; thus, performing actions or debugging code requires conducting C into the editor. Moreover, in the design of TLC, all of the program features in metropolis are the function of the type, as shown in Figure 3. Thus, the designer can use the RTW to generate the required developer as long as the C program is appropriately used together with the TLC syntax. The source code, TLC, and RTW program application flowchart is shown in Figure 4 [8].

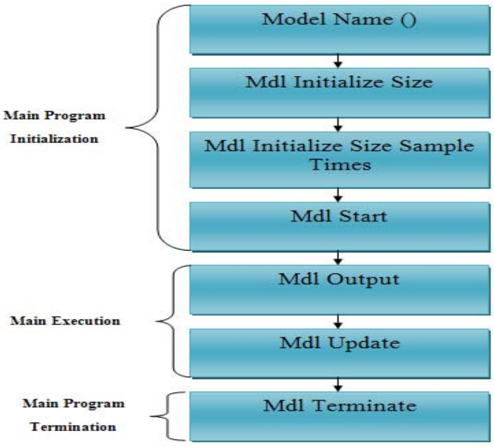

Fig .3. Target Language Compiler grammatical structure[8]

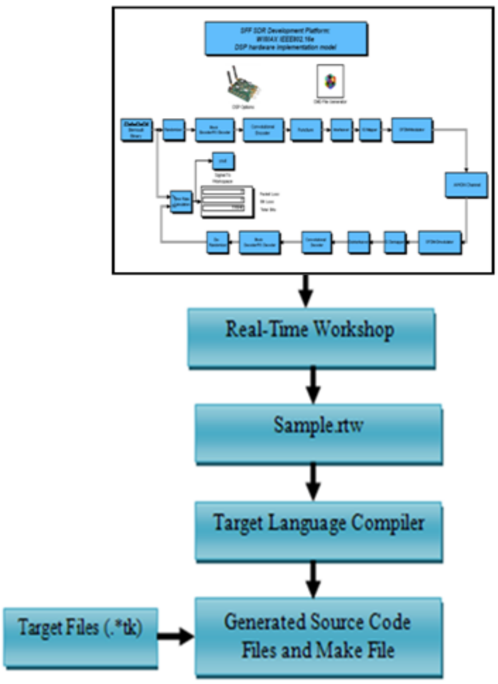

Fig. 4. TLC and the RTW program application flowchart

IV. Block Diagram Of WiMAX IEEE802.16e

The Block diagram in Figure 5

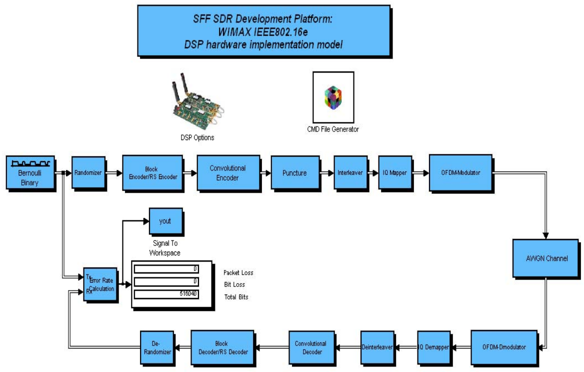

Fig.5. WIMAX IEEE802.16e Software Defined Radio DSP Hardware Implementation.

Represents the whole system model or the signal chain at the base band. The block system is divided into three main sections, namely, the transmitter, the receiver, and the channel. The model has been tested with the channel coding (the part in the dotted box representing the channel coding and decoding). The bit error rate (BER) plots have been obtained for at least 2,000 errors in order to get a good confidence limit.

A. *Transmitter model*

Figure 5 shows how the transmitted signal is generated. The functions of the sub-modules are also briefly described below.

B. *A-1 Data Generation*

Data are generated from a random source and consist of a series of ones and zeros. Since the transmission is done block wise, the size of the data generated depends on the block size used, the modulation scheme used to map the bits to symbols (BPSK, QPSK, 16QAM, and 64QAM [4]. The generated data is passed on to the next stage, either to the FEC block

C. *A-2 Forward error correction*

The data generated are randomized so as to avoid a long run of zeros or ones. The result is ease in carrier recovery at the receiver. The randomized data are encoded when the encoding process consists of a concatenation of an outer Reed-Solomon (RS) code. The implemented RS encoder is derived from a systematic RS Code using field generator GF (2^8) and an inner convolutional code (CC) as an FEC scheme. This means that the first data pass in block format through the RS encoder, and then go across the convolutional encoder. It is a flexible coding process due to the puncturing of the signal, and it allows different coding rates. The last part of the encoder is a process of interleaving to avoid long error bursts using tail biting convolutional codes(CC) with a different coding rate of (puncturing of codes is provided in the standard). Finally, interleaving is done by a two-stage permutation; the first aims to avoid the mapping of adjacent coded bits on adjacent subcarriers, and the second insures that adjacent coded bits are mapped alternately onto more or less significant bits of the constellation, thus avoiding long runs of lowly reliable bits[4].

D. A-3 Symbol mapping

The coded bits are then mapped to form symbols. The modulation scheme used is BPSK, QPSK, 16QAM, or 64QAM with gray coding in the constellation map. The symbol is normalized so that the average power is unity irrespective of the modulation scheme used [4].

E. A-4 Guard Band Intervals:

In OFDM, the data symbols are grouped in a block and called OFDM block symbols. A block consisting of T seconds can be formulated as Ts = LT here, where L is the number of sub stream and Ts is the time it takes to complete one symbol. To avoid interference among symbols while they pass through a wireless channel, the guard time is introduced between the OFDM symbols. The guard time, Ts which is greater than the channel delay spread time then in that scenario, OFDM symbols only experiences the interfere with itself. If the guard time between the two consecutive symbols is increased, then rectification of the symbol interference is possible [4].

F. A.5 IFFT and Cyclic Prefix

The t-th time domain sample at the n-th subcarrier at the output of IFFT is given by

$$X_t = \sum_{n=0}^{N-1} X_n e^{j\frac{2\pi t n}{N}} \quad 0 \le t \le N-1 \qquad (1)$$

Where N is the number of subcarriers and is the data symbol on the n-th subcarrier. From the equation it can inferred that this is equivalent to generation of OFDM symbol. An efficient way of implementing IDFT is by inverse fast Fourier transform (IFFT). Hence IFFT is used in the generation of the OFDM symbol. The addition of a cyclic prefix is done on the time domain symbol obtained after IFFT. The IFFT size ('N' value) is considered as 256 in simulations. These data are fed to the channel that represents the AWGN channel model. OFDM uses cyclic prefix to achieve a channel that is free from ISI. This is accomplished by using circular convolution. Each OFDM symbol is inserted with an acyclic extension of length L that is greater than the delay of the channel. The cyclic prefix combats against ISI in a very simple manner, but it degrades the data rate and efficiency of the system. If the multipath delay in the channel is less than the prefix, then the system will not observe any ISI or Inter carrier Interference (ICI) [4].

G. B. Receiver model

The receiver performs the same operations as the transmitter, but in a reverse order. It also includes operations for synchronization and compensation for the destructive channel. These extra operations are the main focus, and they will be presented and explained throughout the paper. All signal processing is completed in the frequency-domain, and the essential block of the receiver is the FFT. A simplified overview of the receiver is seen in Figure 5.

H. C. System parameters

The reference model specifies a number of parameters that can be found in Table (1, 2).

TABLE (1) SYSTEM PARAMETERS

BW	N-Sampling Factor	G-Cyclic Prefix Time	N-FFT
20MHz	57/50	1/4,1/8,1/16,1/32	256

TABLE (2) SYSTEM PARAMETERS

Modulation	BPSK	QPSK	16-QAM	64-QAM
N cpc	1	2	4	6
N cbps	192	384	768	115

V. SIMULATION &RESULTS:

The simulations implemented in this paper are done in a WIMAX baseband transceiver on a multi-core SDR platform. An OFDM symbol means a group of L data symbols (all the data symbols are transmitted in a parallel manner) and it lasts T seconds, where T=Ls. As the spectrum of OFDM is not band limited (sinc (f) function), linear distortion caused by multipath can cause ISI. To avoid this effect, it is important to transmit a guard interval between OFDM symbols. The duration of each guard interval (Tg) has to be longer than the delay spread (τ) of the channel to ensure that each symbol interferes only with itself. After its introduction, the duration of each symbol is T total=T+Tg. Its introduction also reduces the synchronization problems. The ratio *T*G/*T*d is very often denoted by *G* in WIMAX/802.16e documents. If the channel conditions are good, a lighter value of G has to be used. If the multipath effect is important and the channel is bad, a high value of G is required. For OFDM PHY layers, 802.16e defines the following values for *G:* 1/4, 1/8, 1/16, and 1/32. Channel coding improves the performance significantly. The next simulation was done for the AWGN channel with QPSK modulation scheme and with a different rate tail biting convolutional code. The system model has been tested for PBSK QPSK, 16QAM, and64 QAM modulations with an AWGN channel having the following values for *G:* 1/4, 1/8, 1/16, and 1/32. The simulation results are shown in the figures and Table (3) below.

TABLE (3) SNR REQUIRED TO ATTAIN BER LEVEL.

Modulation	SNR(dB) at G(cyclic prefix)				Level BER
	1/4	1/8	1/16	1/32	
BPSK1/2	0.5	1	1.5	0.2	$10^{-0.29}$
QPSK1/2	3.5	3.8	4	4.1	10^{-1}
QPSK3/4	5.5	6	6.1	6	10^{-1}
16QAM1/2	10	9.9	10	10.1	10^{-1}
16QAM3/4	11.2	12.9	12.5	13	10^{-1}
64QAM2/3	17.5	16.5	16.7	17	10^{-1}
64QAM3/4	18	17.5	17.6	18	10^{-1}

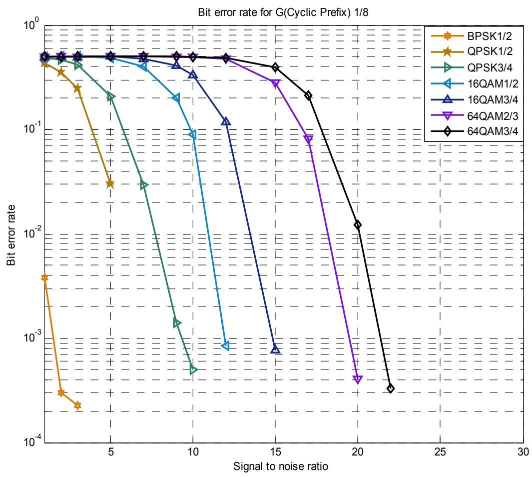

Fig .6. BER of the received symbols (G=1/4, BW=20MHz, AWGN Channel)

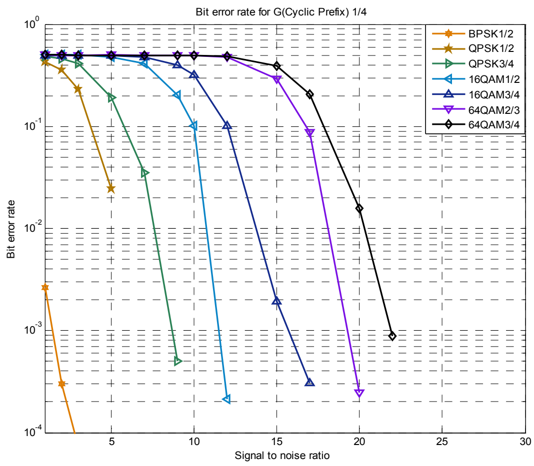

Fig .7. BER of the received symbols (G=1/8, BW=20MHz, AWGN Channel).

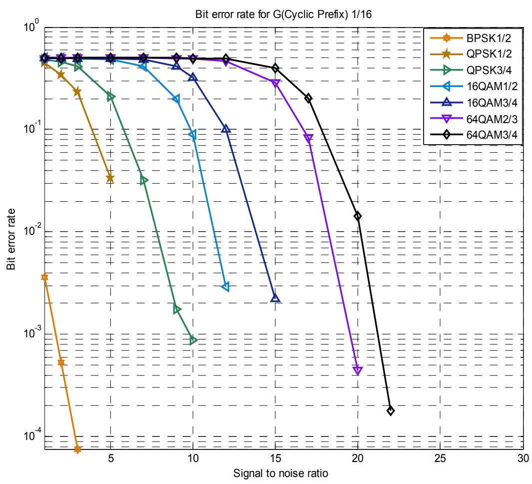

Fig .8. BER of the received symbols (G=1/16, BW=20MHz, AWGN Channel)

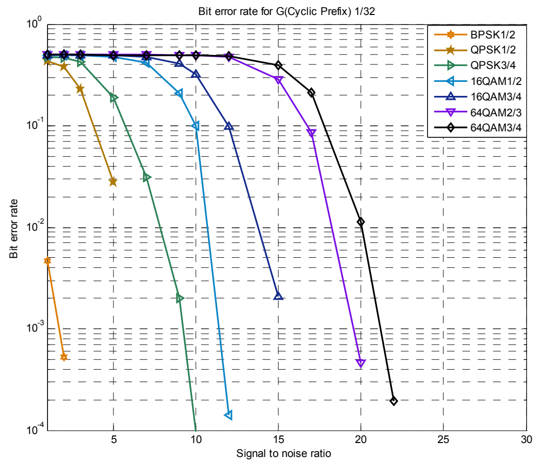

Fig .9. BER of the received symbols (BW=20MHz, AWGN Channel)

VI. Conclusion

The DSP of the SFF SDR Development Platform are completely integrated to the model based design flow, which integrates MATLAB, Simulink, and Real-Time Workshop from The MathWorks. The SFF SCA Development Platform optional package allows SCA waveform development and implementation. The key contribution of this paper was the implementation of the IEEE 802.16e PHY layer using MATLAB in order to evaluate the PHY layer performance under a reference channel model. The implemented PHY layer supports all the modulation and coding schemes, as well as the CP lengths defined in the specification. To keep matters simple, over-sampling was avoided before the AWGN was used. Nonetheless, it can be implemented by minor modifications on the receiver side. The developed Simulator can be easily modified to implement new features and enhance the PHY layer performance. Simulation was the methodology used to investigate the PHY layer performance. The performance evaluation method was mainly concentrated on the effect of channel coding on the PHY layer. The overall system performance was also evaluated under different guard periods. We concluded that BPSK is more power-efficient and needs less bandwidth among all other modulation techniques. In case of bandwidth utilization, the 64QAM modulation requires higher bandwidth and gives excellent data rates as compared with the others. On the other hand, the QPSK and the 16QAM techniques, which are in the middle of these two, need higher bandwidth and are less power-efficient than BPSK. However, they require lesser bandwidth and lower data rates than 64QAM. In addition, BPSK has the lowest BER, while the 64-QAM has highest. There is another conclusion that we arrived at: The inclusion of the Cyclic Prefix reduces the Inter symbol Interference (ISI) that causes the lower BER in the OFDM system but increases the complexity of the system.

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