A Simplified IEEE 802.22 PHY layer in Matlab-Simulink and SDR Platform

Alberto S. Bañacia
Department of Electrical & Electronics Engineering,
University of San Carlos
Nasipit, Talamban, Cebu City, Philippines
abanacia1201@gmail.com

Ramon Miko Gelu III Q. Pedroza
Department of Electrical & Electronics Engineering
University of San Carlos
Nasipit, Talamban, Cebu City, Philippines
mikopedroza.king30@gmail.com

***Abstract* – Due to its ability to provide high data rates and its effectiveness against multi-path delay spread commonly encountered in mobile communications channel, Orthogonal Frequency Division Multiplexing (OFDM) has been the modulation of choice for many current wireless communication standards including IEEE 802.11(WLAN), IEEE 802.16(WiMAX), IEEE 802.22(WRAN) and DVB-T. The IEEE 802.22 standard is now known as the Cognitive radio (CR) standard utilizing white spaces in the TV frequency spectrum and many research efforts are now focused on the use of this TV white space for providing broadband access to rural areas.**

In this paper a simplified IEEE 802.22 physical layer (PHY) was successfully simulated in Matlab-Simulink and implemented in real time in a Software defined radio (SDR) platform through the combination of GNU Radio and the Universal Software Radio Peripheral (USRP). The SDR platform as a testbed was able to demonstrate the flexibility and adaptability required of an OFDM-based PHY layer of the IEEE 802.22 standard.

***Keywords*— OFDM, IEEE 802.22, Software Defined Radio, GNU Radio, USRP1**

I. Introduction

Orthogonal Frequency Division Multiplexing is a multiplexing technique that divides the available bandwidth into orthogonal subcarriers that enables the transmission of multiple data streams over a common broadband medium. It has high spectral efficiency or bandwidth efficiency allowing for faster data transmission in a given bandwidth in the presence of noise. OFDM is also effective against multipath delay commonly encountered in mobile communication channel. The reduction of the symbol rate by N times, where N is the number of orthogonal subcarriers, results in a proportional reduction of the multipath delay spread relative to the symbol period. When frequency fading and interference occur, only a part of the total signal is affected.

The new wireless technologies being used and developed today adopted OFDM as the modulation method. It is perhaps the most spectrally efficient method discovered so far, and it mitigates the severe problem of multipath propagation that causes massive data errors and loss of signal in the microwave and UHF spectrum.The OFDM technique is used in TV broadcasting such as Europe's DVB – T and in wireless standards such as in IEEE 802.11(Wireless Local Area Networks (WLANs) like the WiFI), IEEE 802.16(WiMAX) and IEEE 802.22 (Wireless Regional Area Network) and the recent 4G cellular technology standard LTE [3].

The IEEE 802.22 standard is now known as the Cognitive radio (CR) standard utilizing white spaces in the TV frequency spectrum and many research efforts are now focused on the use of this TV white space for providing broadband access to rural areas. The need for a flexible and adaptable physical layer (PHY) makes OFDM well suited for IEEE 802.22 standard. In this paper a simplified PHY layer was simulated in Matlab-Simulink and implanted in real time using a Software-defined radio (SDR) platform.

SDR allows variation of parameters in software. It is a growing technology in wireless communications where hardware functionalities and processes are transformed into software. With its flexibility, SDR revolutionizes the way wireless communications are implemented. It creates a testbed that enables researchers to test their ideas and algorithms on real transmissions while still keeping the simplicity of a high level programming language environment.

In this study, real time implementation of the simplified PHY layer was successfully implemented through the combined use of the free, open source GNU Radio installed in a personal computer (PC) that runs in an Ubuntu operating system and the Universal Software Radio Peripheral (USRP) hardware. GNU radio provides signal processing blocks to implement software radio processing that includes filters, modulators, and demodulators while the USRP hardware device contains both the motherboard and the daughterboard. It serves as a digital baseband and IF section of a radio communication system that essentially performs all the high-speed general purpose operations, like digital up- and down-conversion and decimation and interpolation, on the Field Programmable Gate Array (FPGA).

II. System Overview and Experimental Setup

The goal of this project was to implement an OFDM-based simplified PHY layer of the IEEE 802.22 standard in MATLAB 2014 through its blocks in the Simulink library and using GNU Radio and USRP platform simulate and implement the system in real time. A 3-GHz Hameg spectrum analyzer was used as a receiver during real time transmission.

A. MATLAB Simulink Implementation

In the MATLAB implementation of the project, two sets of OFDM systems were made and simulated through MATLAB Simulink. First, a basic OFDM transmitter and receiver system and the second one was the simplified OFDM-based IEEE 802.22 PHY layer.

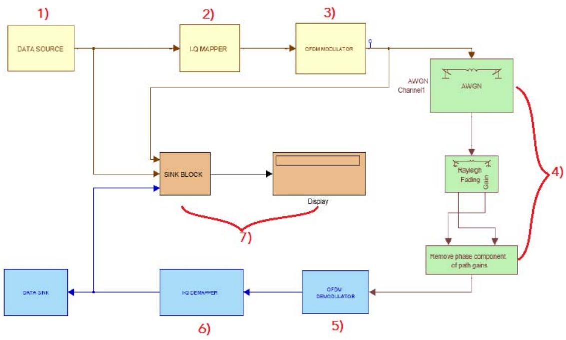

Figure 1. OFDM Transmitter and Receiver Model

Figure 1 shows the OFDM transmitter and receiver model used to implement OFDM in MATLAB Simulink. The data source block is where the input data is generated, here a random integer generator was used. The IQ Mapper block modulates the data source using 64 QAM. The OFDM Modulator block performs the Inverse Fast Fourier Transform process, and an IFFT bock was used. A selector block was then connected to add ¼ cyclic prefix. The AWGN block is used to emulate an actual transmission channel where the SNR was varied from -50 to 0 dB. The OFDM Demodulator block performs the FFT process. The IQ Demapper block demodulates the data using 64 QAM. The signal is now recovered and computed with its error rate which is shown on the display block.

The basic OFDM system was implemented in MATLAB Simulink. By varying the frame size, the performance of the system was tested and simulated. Its properties were verified in MATLAB with the different transmitter tests. The OFDM system was then modified to follow the IEEE 802.22 standard.

Table 1 shows the IEEE 802.22 parameters chosen for the purpose of this study. To perform subcarrier allocation, a multiport selector and matrix concatenate blocks were added in the OFDM modulator block. Constant blocks were used to represent the guard and pilot carriers.

Table 1 Simplified IEEE 802.22 PHY Parameters

Parameter	**Value**				**Symbol**
Channel Width	6 MHz				
Basic Sampling Frequency	**6.586 MHz**				F_S
FFT Size	**2048**				N_{FFT}
Cyclic Prefix	1/32	1/16	1/8	**1/4**	CP
Guard subcarriers	**184 L+1 DC+183 R=368**				N_{LG}, N_{DC}, N_{RG}
Pilots	**240**				N_P
Data subcarriers	**1440**				N_D
Signal bandwidth $(N_D+N_P+N_{DC})\Delta f$	5.627 MHz				
Modulation	QPSK, 16-QAM, **64-QAM**				

B. GNU Radio Implementation and Simulation

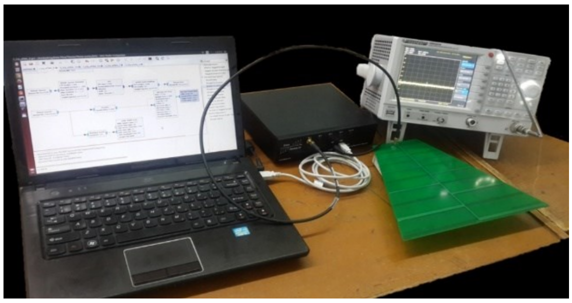

Figure 2. Hardware setup

Figure 2 shows the hardware setup in implementing the OFDM-based simplified PYH layer of IEEE 802.22 standard in an SDR platform.. The USRP was connected to a PC with GNU Radio Software installed in a PC running on Ubuntu via USB 2.0 connection. The USRP architecture includes 64MS/s dual ADC, and 128MS/s DAC. The hardware operates from DC to 6 GHz. The RF front in the system consists of the WBX daughterboard which operates from 50 to 2200 MHz, bandwidth capability up to 40 MHz and can provide up to 100mW output power with a noise figure of 5dB and a logarithmic LP0410 antenna connected through an SMA cable which allows frequency operation from 400 MHz to 1 GHz with a gain of 5 to 6 dBi. This allows the operating frequency used in the project which ranges from 596 to 602 MHz.

The antenna used was a Log Periodic PCB directional antenna (LP0410). It allows an operation of frequencies ranging from 400 MHz to 1 GHz with a gain of 5 to 6 dBi gain.

Figure 3 shows the simplified IEEE 802.22 PHY layer GNU radio signal flow graph. The random source block outputs random byte data samples with a maximum value of 255. The QAM modulator block modulates the input data through IQ mapping using 64 QAM. The streams to tagged streams block was used to group data into frames. The OFDM carrier allocator block was used for subcarrier mapping with an FFT length equal to 2048. The FFT block was set to reverse to perform inverse Fast Fourier Transform. The OFDM cyclic prefixer block was set to add ¼ cyclic prefix on each OFDM symbol. The WX_GUI FFT sink displays the FFT plot of the data. The Multiply constant block was used to scale the data by 1/√N. The UHD USRP sink block was used to connect to the USRP1. The center frequency was set to 599 MHz, which is the operating frequency used with a bandwidth of 6 MHz. The sample rate was set to 8 MSps, this is the highest sample rate that the USB 2.0 allows.

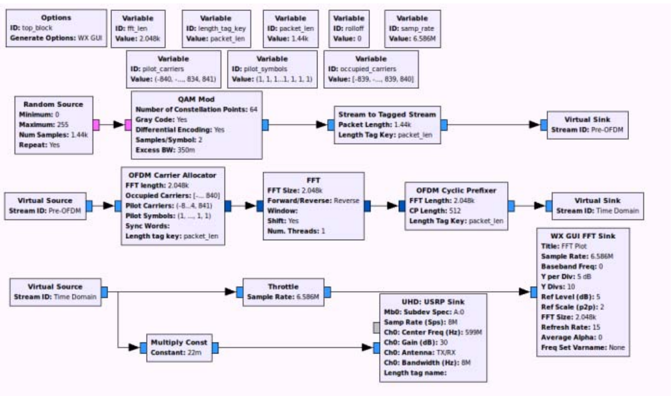

Figure 3. Simplified IEEE 802.22 PHY layer GNU radio Signal Flow Graph

III. RESULTS AND DISCUSSION

A. Bit Error Rate

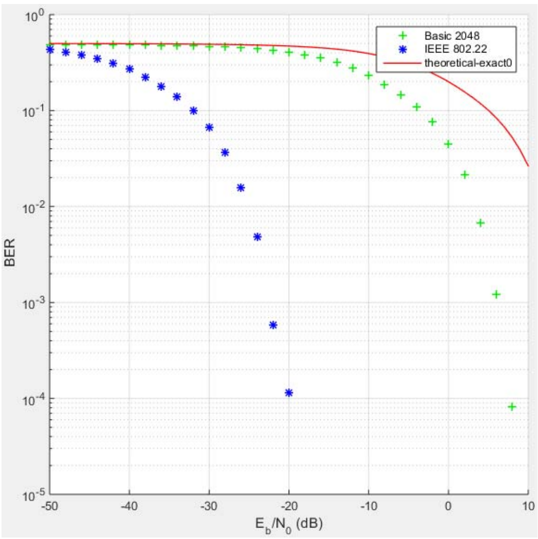

Figure 4. Simplified IEEE 802.22 PHY layer vs. Basic OFDM with 2048 FFT Length

Figure 4 shows the Bit Error Rate (BER) performance comparison between the IEEE 802.22 standard and the basic OFDM with 2048 FFT length. Both samples starts at the theoretical value of the BER. At -30 Eb/No, the BER of IEEE 802.22 standard starts to slope downward thus approaching to 0 while the basic OFDM with 2048 FFT length is still close to the theoretical values. The simplified IEEE 802.22 fast approaches to zero at -20 Eb/No while the basic OFDM with 2048 FFT Length at 0 Eb/No. The BER performance of the former is far better that of the latter with 2048 FFT length which results to good data transmission.

For the simplified IEEE 802.22 PHY layer, a good signal can stilll be recovered even at -20 Eb/No. While for the basic OFDM with an FFT length of 2048, the limit of Eb/No value to still recover a good signal is at approximately 10 Eb/No.

B. Comparison of MATLAB Simulink and GNU Radio Outputs of Simplified OFDM-based IEEE 802.22 PHY

MATLAB Simulink

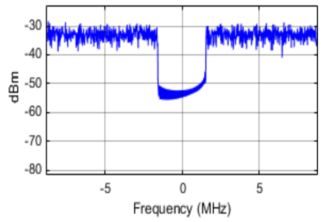

Figure 5. Spectrum Output of Matlab-Simulink (2048 FFT)

GNU Radio

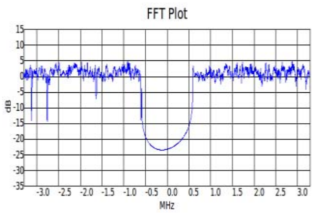

Figure 6. FFT Plot of GNU Radio(2048 FFT)

Figures 5 and 6 are the comparison of the spectrum outputs of the OFDM-based simplified IEEE 802.22 PHY layer simulated in MATLAB Simulink and GNU Radio. Both simulations have the same parameters of 64 QAM modulation, ¼ cyclic prefix, 1440 frame size, and 2048 FFT size. Both figures show similar outputs where there is a portion at the center of the signal collapsed.

Comparing the results from both platforms, it can be observed that they are similar. The effects of varying the samples/frame in MATLAB Simulink and varying the packet length in GNU Radio have the same effects on the signal. The FFT size dictates the total number of available subcarriers. The FFT size used in MATLAB Simulink was 64, this means that the available number of data subcarriers is 64. While in GNU Radio, 2048 FFT size was used, but only had 2046 available subcarriers, since the other 2 was used as pilot.

When the samples/frame in MATLAB and the packet length in GNU Radio were varied, the signal changes. When it was changed to a value half of its FFT size, it was seen in the output that half of the signal collapsed which means that only half of the subcarriers were used. When it was changed to a quarter of its FFT size, only a quarter of the subcarriers were used as observed in the output. OFDM allows the turning on and off of the subcarriers. So when certain subcarriers are not needed, one can just switch off the said subcarriers.

C. Real-time transmission of Simplified IEEE 802.22PHY

Two types of transmissions were done. The first was the wired transmission where the USRP1 was connected to the 3-GHZ Hameg spectrum analyzer using a SMA-BNC cable. The second set of tests were in wireless transmission where the spectrum analyzer was moved away from the transmitter

In both cases, the signal is centered at 599 MHz, which is the center frequency of the 596 – 602 MHz TV channel that was used. It has an effective bandwidth of 5.6 MHz.

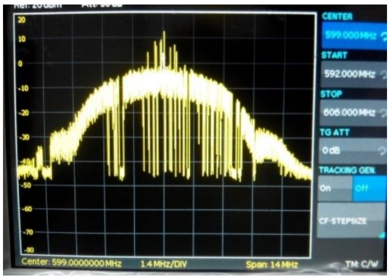

Figure 7. Output of Wired Transmission with 20 dB Gain as seen in Hameg Spectrum Analyzer

With the receiver antenna and transmitter antenna in direct contact, the gain set in the UHD sink was set to 20 dB. The peak power that the spectrum analyzer captures is at about -3 dBm. The succeeding tests were done with UHD sink Gain set to 10, 0, -10, and -20 respectively.

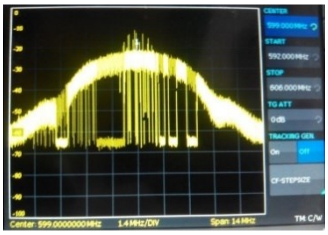

Figure 8. Output of Wireless Transmission 5 ft. Away As seen in Hameg Spectrum Analyzer

Figure 8 shows the output when the spectrum analyzer was placed 5 feet away of the transmitter. Compared to figure 11, the peak power has almost equal value. When the spectrum analyzer was moved to 20 ft., the power went down to below -40 dB.

IV. CONCLUSION

In this paper a simplified IEEE 802.22 physical layer (PHY) was successfully simulated in Matlab-Simulink and implemented in real time in a Software defined radio (SDR) platform through the combination of GNU Radio and the Universal Software Radio Peripheral (USRP). The SDR platform as a testbed was able to demonstrate the flexibility and adaptability required of an OFDM-based PHY layer of the IEEE 802.22 standard**.** Both simulations have the same parameters of 64 QAM modulation, ¼ cyclic prefix, 1440 frame size, and 2048 FFT size.

The different tests done in MATLAB and GNU Radio gave comparable results. The use of GNU Radio and USRP provided a reconfigurable and flexible Software defined radio platform that made possible real time transmission of the simplified OFDM-based IEEE 802.22 PHY layer.

REFERENCES

[1] Louis Frenzel, "Mobile Dev Design," Available: file:///H:/Sept%201/OFDM/Orthogonal%20Frequency%20Division%20Multiplexing%20(OFDM)%20Tutorial%20%20%20Learning%20Resources%20content%20from%20Mobile%20Dev%20&%20Design.htm.

[2] P. Balister and J. Reed, "USRP Hardware and Software Description," Department of Electrical and Compueter Engineering, Virginia Polytechnic Institute and State University, Blacksburg, 2006.

[3] A. Verduin, "GNU Radio Wireless Protocol Analysis Approach,"Universiteit Van Amsterdam, 2008.

[4] C. Cordeiro, K. Challapali and D. Birru, "IEEE 802.22: An Introduction to the First Wireless Standard based on Cognitive Radios,"Philips Research North America/ Wireless Communication and Networking Department, Briarcliff Manor, USA, 2006.

[5] C. Sonntag, "Orthogonal Frequency Division Multiplexing (OFDM) Implementation as Part of a Software Defined Radio (SDR) Environment,"Department of Electrical and Electronics Engineering, University of Stellenbosch, Private Bag 1, Matieland, 7602,South Africa, 2005.

[6] D. T. Nguyen, "*Implementation of OFDM Systems using GNU Radio and USRP,"*School of ELectrical, Computer and Telecommunications Engineering, University of Wollongon, 2013.

[7] A. L. Intini, "Orthogonal Frequency Division Multiplexing for Wireless Networks,"Electrical and Computer Engineering Department, University of California, Santa Barbara, 2000.