Design and Simulation of the IEEE 802.16a physical layer

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Abstract

Fixed Broadband Wireless Access (BWA) is a technology that offers high-speed voice, video and data services for the "last mile," which is presently dominated by the cable and digital subscriber line (DSL) technologies. The biggest advantage BWA has over its wired competitors is its increased capacity and ease of deployment, since networks can be created in just weeks by deploying a small number of base stations on buildings or poles to create high-capacity wireless access systems. The biggest obstacles for BWA deployment, on the other hand, are the cost of the customer premises equipment (CPE) and the overall performance of the system [1]. The recently approved IEEE 802.16a [2] is a new BWA standard operating in the 2-11 GHz range, and is touted as an important step towards widespread adoption of this technology.

The objective of this project is to model and simulate the IEEE 802.16a OFDM physical layer using C language. The simulations will compare the performance of different receiver models, while noting their complexity. The developed simulation will also provide a framework for developing new receiver models for 802.16a systems.

I. Introduction

Fixed Broadband Wireless Access (BWA) is a new " last mile" access technology that offers high-speed voice, video, and data services, which is presently dominated by the cable and digital subscriber line (DSL) technologies. BWA has a big advantage over its wired competitors in terms of capacity and ease of deployment. Wired broadband solutions require some existing infrastructure, like cable or telephone lines, which make deployment to underserved areas problematic and costly. Additionally, installation and maintenance of these networks typically require a technician to visit the customer premises, increasing the overall costs for the Internet Service Provider. BWA requires little infrastructure, and could theoretically be user-installed. Networks could be created in a short time by deploying a small number of base stations on buildings or poles to create high-capacity wireless access systems [1]. However, the wide-scale adoption of BWA will be strongly determined by its ability to overcome cost and performance barriers. If BWA can meet these challenges, it could easily be the next big revolution in wireless similar to Wireless LANs [3, 4].

The IEEE Wireless Metropolitan Area Networks (WirelessMAN) Standard 802.16a is a new standard for BWA [2]. Announced on January 30, 2003, this extension of the 802.16 standard covers fixed broadband wireless access in licensed and unlicensed spectrum from 2 to 11 GHz. Chair of the 802.16a working group Roger Marks proclaims, "The new IEEE 802.16a standard reshapes the broadband landscape. It closes the first-mile gap, giving users an easily installable, wire-free method to access core networks for multimedia applications [3]." License-exempt Wireless Internet Service Providers (WISPs) are thus given a boost through this standardization.

Some analysts believe that WISPs will become a big factor in shaping the broadband landscape in the years to come [4].

The goal of this project is to address one of the major hurdles in deployment of BWA, which is its performance within the hostile wireless channel. This project aims to evaluate the effects of different receiver models on the performance of the 802.16a physical layer specification. The design of the OFDM receiver is not part of the IEEE 802.16a standard, and is thus left up to manufacturers to come up with robust and cost effective implementations. The project will evaluate different receiver algorithms through simulation in C language. The IEEE 802.16a standard specifies a 256-point transform OFDM. This project will simulate the 256-point transform OFDM physical layer, since this air interface is mandatory for operation in license-exempt bands [5]. The project will model, simulate, and then, evaluate different receiver algorithm in terms of their performance, while noting the computational complexity for each of these algorithms.

The project will produce a written report, oral presentation, and an 802.16a physical layer simulator that will be released to the public. These deliverables could provide a good starting point for companies and universities interested in 802.16a. The report will evaluate some standard receiver models, while the simulator will provide a framework for developing and testing new models. Finally, the oral presentation will give a graduate-level class an overview of 802.16a, a look at some models for OFDM implementation, and an example of a communications system simulator.

II. Approach

The project will be composed of four major phases: research, modeling, simulation, and analysis.

A. Research

Initially, an intensive study of the 802.16a OFDM physical layer shall be performed, where the key issues in the design of an OFDM system that communicates through a fixed broadband wireless channel will be thoroughly analyzed. The issues facing OFDM and its performance in the indoor wireless channel have been studied extensively in the literature [6, 7, 8]. These results and analyses shall then be extended into the fixed broadband wireless case.

B. Modeling

The 802.16a OFDM physical layer will be modeled and simulated in C language. C language is a dataflow programming language that is suitable for communication system modeling and simulation [9]. C language provides a relevant interface that is useful for interactive control of key simulation parameters, which provides better intuitive understanding of the system.

C. Simulation

A C language system simulation will provide a suitable environment for the effective analysis of the performance of the 802.16a OFDM physical layer. A waveform level, discrete, baseband model will be developed, where semi-analytical Monte Carlo simulation runs will estimate the system performance. The semi-analytical simulation gives a good trade-off between computational complexity and simulation accuracy between a full Monte Carlo simulation and a purely analytical analysis, respectively [10]. Various simulation parameters can be automatically chosen by the simulator for predefined simulation runs, or interactively changed by the user while a simulation is running. These parameters include a choice between the uplink and downlink scenario, the various rates supported by the standard (QPSK, 16-QAM, and 64-QAM), and the length of the cyclic prefix.

The block diagram of an 802.16a OFDM physical layer model is shown in Fig. 1.

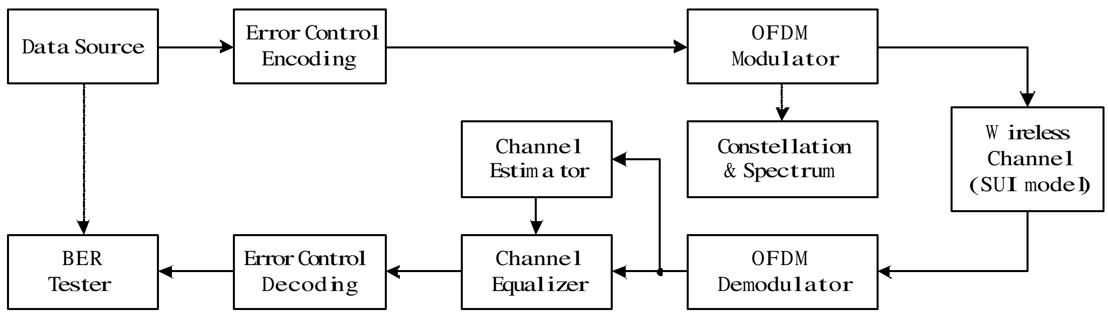


Figure 1. 802.16a Physical Layer Block Diagram

Each block shall be modeled as follows:

a. **Channel**: A discrete channel model based on the Stanford University Interim (SUI) [11] model will be used. This model has a set of six typical channels which were selected for the three terrain types that are typical of the continental US [12]. These wireless channels are characterized by path loss, multipath delay spread, fading characteristics, Doppler spread, co-channel and adjacent channel interference, and antenna gain reduction factor. The user will also be given the option of modifying the channel characteristics while the simulation is running.

b. **OFDM Modulator and Demodulator**: The OFDM modulator and demodulator blocks would be developed using standard IFFT and FFT blocks provided in C language. Perfect clock, symbol, and frame synchronization is assumed, and the effects of synchronization error will not be discussed in this project.

c. **Channel Estimator**: The channel estimator will obtain a depiction of the channel state to combat the effects of the channel using an equalizer. Block estimation algorithm, the Least Squares (LS) [6] will be analyzed in terms of performance and complexity.

d. **Channel Equalizer**: The channel equalizer will use the output from the channel estimator to ameliorate the effects of the channel and improve the performance of the system. A frequency domain equalizer will be thoroughly investigated in terms of its performance and complexity. Also, the performance of the system with and without the equalizer will be evaluated.

e. **Error Control Coding**: Error control coding is essential for OFDM systems since it compensates for the bit errors that are inevitable in times of deep fade in the channel. The Reed Solomon encoder and decoder, convolutional encoder and Viterbi decoder, and the randomizer/de-randomizer and interleaver/de-interleaver will be implemented, and its effect on the overall bit error rate (BER) performance will be analyzed.

f. **Performance Analysis Blocks:** To determine the qualitative and quantitative performance of the system and give a good intuitive understanding of the effects of certain parameters on the system, C language blocks that display performance curves will be developed for the simulation. These include bit error rate testers, spectrum analyzers, and constellation plotters.

D. Analysis

After generating the model of the OFDM system and performing simulation runs for various permutations of the system parameters (details of which are provided in the next section), extensive analyses on the results of the simulation will be performed. The effect of the channel parameters, the channel estimation method, the equalization structure, and the error control coding on the overall system BER performance will be deduced and compared to the theoretical results presented in the various papers [7, 8]. Key insights on efficient 802.16a receiver design and implementation will be discussed and clearly presented. The initial top-level C language transmitter and receiver block diagrams have already been developed and are shown in figure 2 and figure 3.

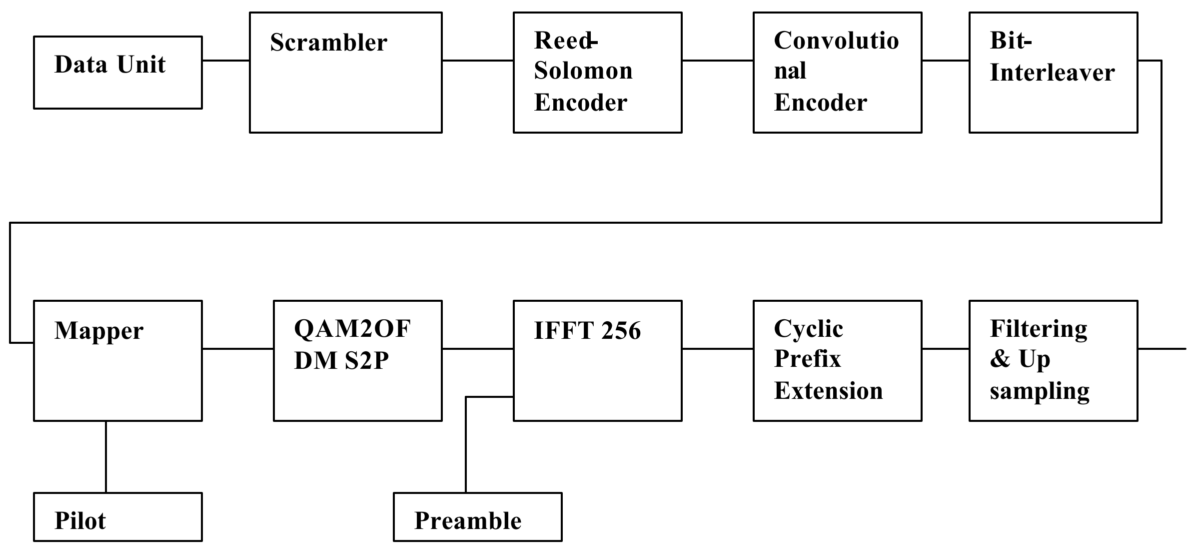


Figure 2: Transmitter block diagram

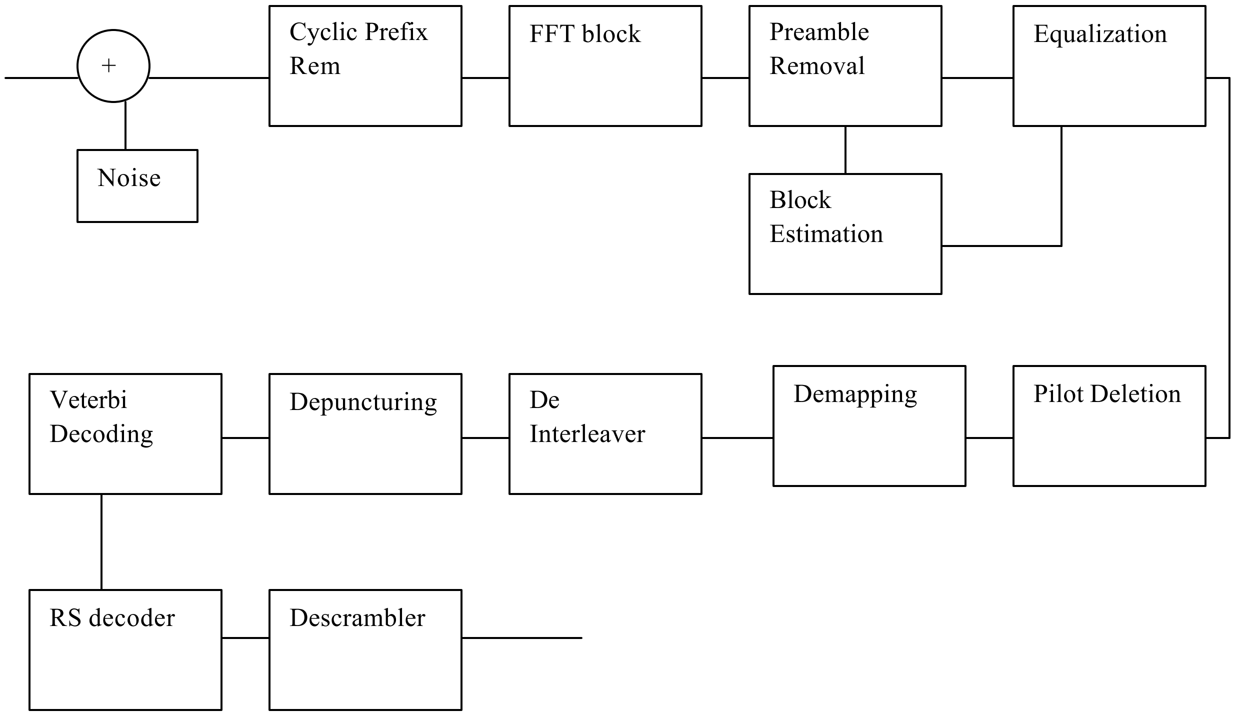
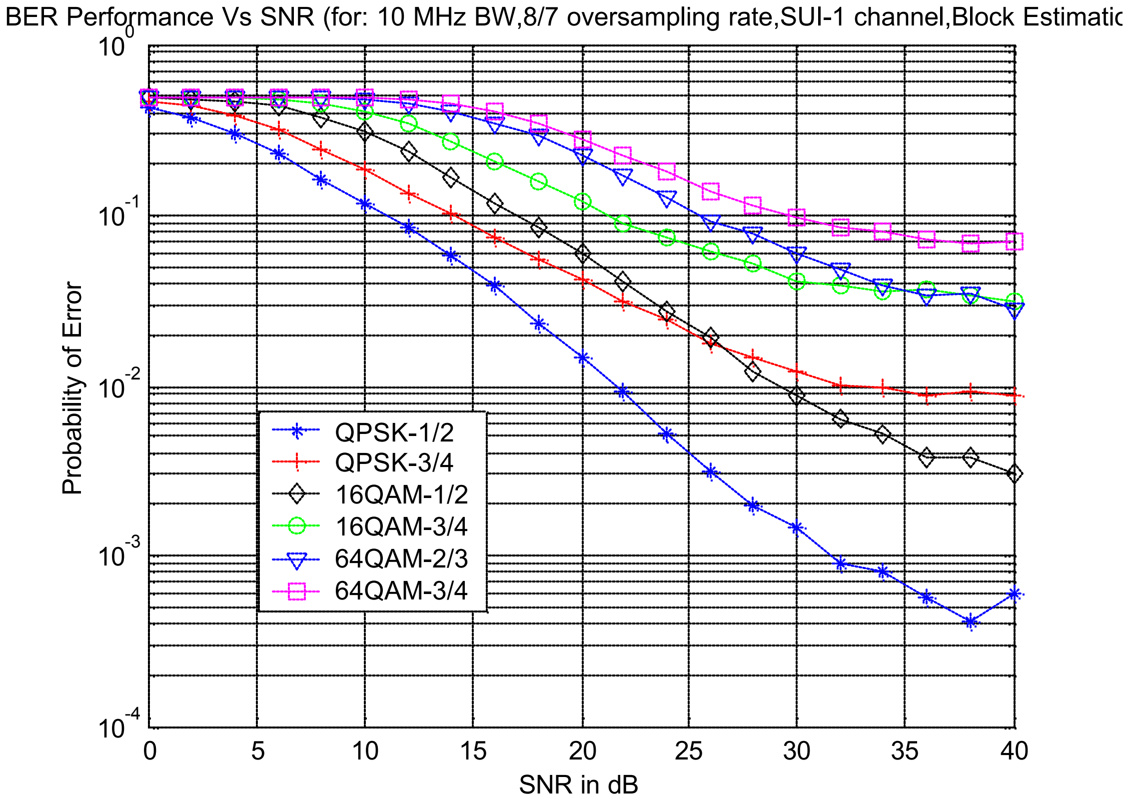


Figure 3: Receiver block diagram

III. Expected Outcomes

The first and most significant deliverable of this project will be a C language simulation of the OFDM physical layer of an 802.16a system. This includes modulation and decoding of OFDM and error control coding. An implementation of block estimation algorithm with a frequency domain equalizer will be performed using this simulation for six different bit rates specified in the standard. Six different channel models specified by Stanford University (Stanford University Interim models) will be used to simulate the broadband wireless channel.

A key performance measure of a wireless communication system is the BER. Curves of BER versus the signal to noise ratio (SNR) will be generated for the above modes of operation. These curves will also be plotted for a system that does not use channel coding, and thus the coding gain of the system will be determined. The BER curves will be used to compare the performance of the estimation algorithms used. Computational complexity of each model will be noted. Fading plots for the different channel models indicating the signal strength as a function of time will also be generated. These will provide a comprehensive evaluation of the performance of the OFDM physical layer for different states of the wireless channel.



This project will provide the researchers and the class an in-depth understanding of the advantages and challenges involved in the deployment of a fixed broadband wireless network. A keen understanding of OFDM as specified in the 802.16a standard and various receiver algorithms for OFDM will be gained. The simulation tool that will be developed as part of this project could also be distributed to chip and equipment manufacturers to test their designs for commercial 802.16a hardware. This tool could also be used by other researchers in the field of wireless broadband access to experiment with new algorithms for 802.16a systems.

Broadband wireless networks are key to promising applications like high-speed wireless Internet access and multimedia services such as video conferencing. BWA is expected to address the “last mile” issue that is currently dominated by DSL and cable technologies. Fixed wireless networks may prove to be extremely useful in regions where deployment of wired systems is not feasible. This project will provide valuable insight on the challenges faced and obstacles that have to be overcome before the successful commercial deployment of 802.16a networks could be realized.

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