Design and Implementation of Orthogonal Frequency Division Multiplexing (OFDM) Signaling

Research Project Description

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Student Involvement

The Electrical Engineering Senior Capstone Project is intended to give each student experience in completing a sophisticated design project that spans most of the senior year. Planning, management of time, allocation of responsibility, documentation, and presentation of the results are integrated with the technical design task. The students work with one or two faculty advisors who have expertise in the project research area. The student is fully responsible for the design project, with the advisor(s) acting as guide and mentor. Each student is expected to work an eight hour lab period each week from October through May.

Introduction

A common problem found in high speed communication is inter-symbol interference (ISI). ISI occurs when a transmission interferes with itself and the receiver cannot decode the transmission correctly. For example, in a wireless communication system such as that shown in Figure 1, the same transmission is sent in all directions. Because the signal reflects from large objects such as mountains or buildings, the receiver sees more than one copy of the signal. In communication terminology, this is called multipath. Since the indirect paths take more time to travel to the receiver, the delayed copies of the signal interfere with the direct signal, causing ISI.

Objective of Research

This project will focus on Orthogonal Frequency Division Multiplexing (OFDM) research, simulation, and implementation. OFDM is especially suitable for high speed communication due to its resistance to ISI. As communication systems increase their information transfer speed, the time for each transmission necessarily becomes shorter. Since the delay time caused by multipath remains constant, ISI becomes a limitation in high-data-rate communication [1]. OFDM avoids this problem by sending many low speed transmissions simultaneously. For example, Figure 2 shows two ways to transmit the same four pieces of binary data. Suppose that this transmission takes four seconds. Then, each piece of data in the left picture has a duration of one second. On the other hand, OFDM would send the four pieces simultaneously as shown on the right. In this case, each piece of data has a duration of four seconds. This longer duration leads to less problems with ISI. Another reason to consider OFDM is low-complexity implementation for high speed systems compared to traditional single carrier techniques [2].

After researching OFDM, a versatile MATLAB simulation will be completed. Then, these simulation results will be used as a guide to implement OFDM on a Texas Instruments TMSC6201 DSP board for real-time processing. The MATLAB code will need to be converted to C programming language to run on the DSP board. To test the DSP code, we will verify if the input and output vectors of the MATLAB simulation and DSP implementation agree.

Significance of Research in Discipline

With the rapid growth of digital communication in recent years, the need for high-speed data transmission has increased. New multicarrier modulation techniques such as OFDM are currently being implemented to keep up with the demand for more communication capacity. Multicarrier communication systems "were first conceived and implemented in the 1960s, but it was not until their all-digital implementation with the FFT that their attractive features were unraveled and sparked widespread interest for adoption in various single-user and multiple access (MA) communication standards" [2]. The processing power of modern digital signal processors has increased to a point where OFDM has become feasible and economical. Examining the patents, journal articles, and books available on OFDM, it is clear that this technique will have an impact on the future of communication. See the references section (starting on page 6) for a condensed bibliography and list of patents related to this topic. Since many communication systems being developed use OFDM, it is a worthwhile research topic. Some examples of current applications using OFDM include GSTN (General Switched Telephone Network), Cellular radio, DSL & ADSL modems, DAB (Digital Audio Broadcasting) radio, DVB-T (Terrestrial Digital Video Broadcasting), HDTV broadcasting, HYPERLAN/2 (High Performance Local Area Network standard), and the wireless networking standard IEEE 802.11 [1] [3] [4].

Methodology

This project consists of MATLAB simulation and DSP implementation. Figure 3 shows a simplified flowchart of the MATLAB simulation code. The transmitter first converts the input data from a serial stream to parallel sets. Each set of data contains one symbol, S_i, for each subcarrier. For example, a set of four data would be [S_0 S_1 S_2 S_3]. Before performing the Inverse Fast Fourier Transform (IFFT), this example data set is arranged on the horizontal axis in the frequency domain as shown in Figure 4. This symmetrical arrangement about the vertical axis is necessary for using the IFFT to manipulate this data. An inverse Fourier transform converts the frequency domain data set into samples of the corresponding time domain representation of this data. Specifically, the IFFT is useful for OFDM because it generates samples of a waveform with frequency components satisfying orthogonality conditions. Then, the parallel to serial block creates the OFDM signal by sequentially outputting the time domain samples.

The channel simulation allows examination of common wireless channel characteristics such as noise, multipath, and clipping [5]. By adding random data to the transmitted signal, simple noise is simulated. Multipath simulation involves adding attenuated and delayed copies of the transmitted signal to the original. This simulates the problem in wireless communication when the signal propagates on many paths. For example, a receiver may see a signal via a direct path as well as a path that bounces off a building. Finally, clipping simulates the problem of amplifier saturation. This addresses a practical implementation problem in OFDM where the peak to average power ratio is high.

The receiver performs the inverse of the transmitter. First, the OFDM data are split from a serial stream into parallel sets. The Fast Fourier Transform (FFT) converts the time domain samples back into a frequency domain representation. The magnitudes of the frequency components correspond to the original data. Finally, the parallel to serial block converts this parallel data into a serial stream to recover the original input data.

Now that the MATLAB code is mostly complete, its functionality must be duplicated on the DSP board. By writing simple test simulations, the functionality of the DSP tools is being explored. The first major milestone in these simulations was to generate and output simple sinusoidal waveforms using an IFFT routine. Once the DSP tools are understood, the MATLAB code will be translated into C for the DSP board. When this is complete, the testing phase will involve verifying that the DSP board produces results consistent with the MATLAB code. Also, once the OFDM system works correctly, the characteristics of the OFDM transmission will be examined. This may include phase shift and synchronization techniques.

Results

The current version of the MATLAB simulation accepts binary, text, or sound as input. It then generates the corresponding OFDM transmission according to variable setup parameters.

Figure 5 shows one example of the graphs generated by the current MATLAB code. The upper left plot is the input sound file. After modulation, the corresponding OFDM transmission is shown on the upper right. For this example, a perfect channel was assumed which means that the received signal (lower right) exactly matches the transmitted. Finally, the received OFDM signal is demodulated to reproduce the original input data, shown in the lower left plot.

Figure 6 is a screenshot of the OFDM MATLAB code running with a multipath channel simulation. The lower left plot shows the frequency components of the outgoing transmission. The lower right plot shows the received signal and how it is affected by a multipath channel. The upper plots show that even with multipath, using OFDM allows the data to be recovered.

For comparison of OFDM to other communication systems, a simulation using single carrier QAM will be implemented in MATLAB. This simulation should show that for a given multipath delay, OFDM performs better than a traditional single carrier system.

When the MATLAB code is translated to C and compiled for the DSP board, it is expected that the MATLAB and DSP outputs will match, given the same input data. The DSP implementation will also help us assess some practical limitations of OFDM versus the ideal simulation in MATLAB.

Conclusions

A MATLAB program has been written to investigate applications of OFDM to a broad range of communication systems. This program will be especially valuable for simulating systems that are too complex to analyze theoretically, and will be placed on the EE department web page for use by future researchers including Bradley students. The development of real-time code for a contemporary digital signal processing integrated circuit will enable the comparison of simulation results with a hardware realization.

References

Bibliography

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[2] Wang, Zhengdao, and Georgios B. Giannakis. “Wireless Multicarrier Communications.” *IEEE Signal Processing Magazine* (May, 2000): 29-48

[3] Bingham, John A. C. “Multicarrier Modulation for Data Transmission: An Idea Whose Time Has Come.” *IEEE Communications Magazine* (May, 1990): 5-14

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[6] Mitra, Sanjit K. *Digital Signal Processing: A Computer-Based Approach*. New York: McGraw-Hill, 2001.

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[8] Bahai, Ahmad R. S., and Burton R. Saltzberg. *Multi-Carrier Digital Comunications:Theory and Applications of OFDM*. New York: Kluwer Academic/Plenum Publishers, 1999.

[9] Lawrey, Eric. OFDM Wireless Technology. 11 May 2000. 7 Nov. 2000. http://www.eng.jcu.edu.au/eric/thesis/Thesis.htm

References (cont.)

Patent History

Class/Subclass

370	Multiplex Communications
370/203	Generalized Orthogonal or Special Mathematical Techniques
370/208	Particular set of orthogonal functions (subset of 203)
708	Electrical Computers: Arithmetic Processing and Calculating
708/400	Transform (subset of 200)
708/403	Fourier (subset of 400)
708/404	Fast Fourier Transform (subset of 403)

Historical

3,488,4555	Orthogonal Frequency Division Multiplexing (Jan 6, 1970)

Current

<u>370/208</u>

6,125,124	Synchronization and sampling frequency in an apparatus receiving OFDM modulated transmissions (Sept 26, 2000)
6,021,110	OFDM timing and frequency recovery system (Feb 1, 2000)

<u>708/404</u>

6,115,728	Fast fourier transforming apparatus and method, variable bit reverse circuit, inverse fast fourier transforming apparatus and method, and OFDM receiver and transmitter (Sept 5, 2000)

References (cont.)

Visual Materials

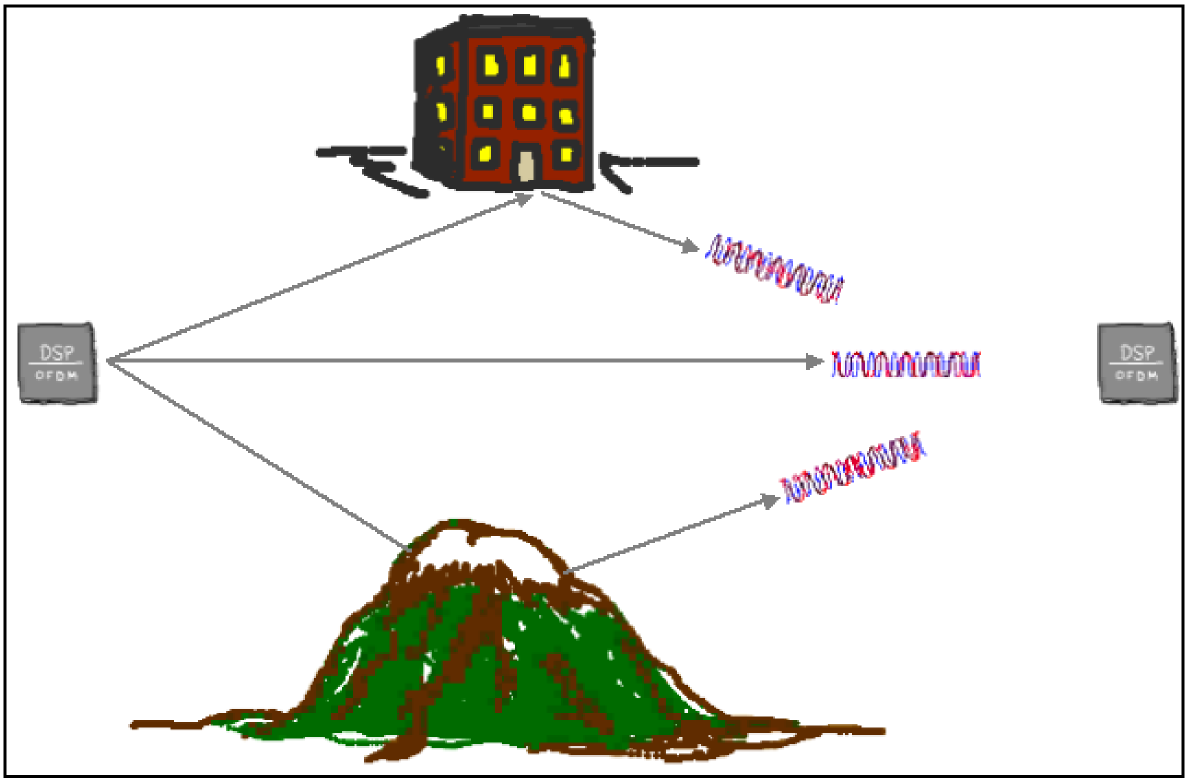

Figure 1: Multipath Demonstration

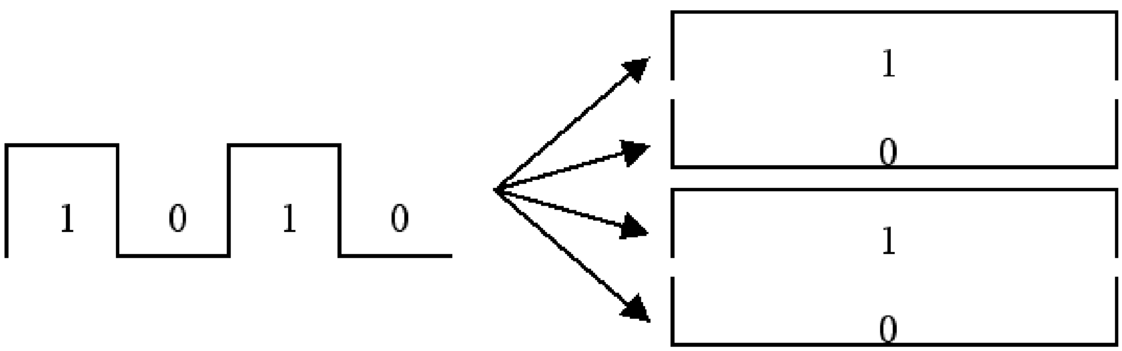

Figure 2: Traditional vs. OFDM Communication

References (cont.)

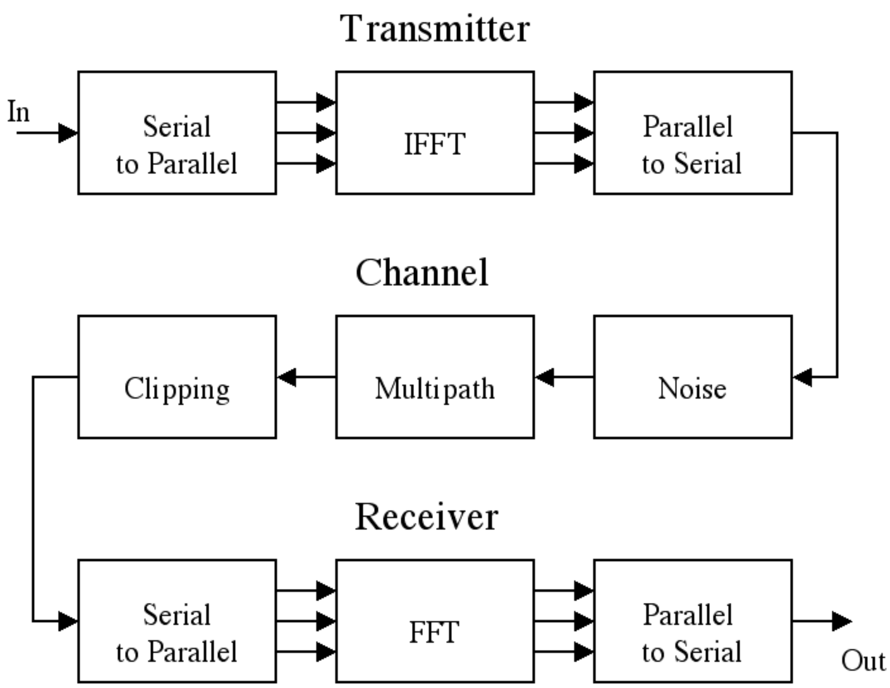

Figure 3: OFDM Simulation Flowchart

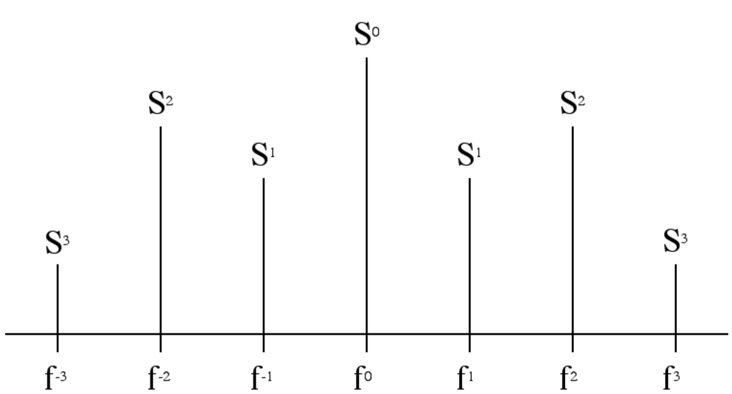

Figure 4: Frequency Domain Distribution of Symbols

References (cont.)

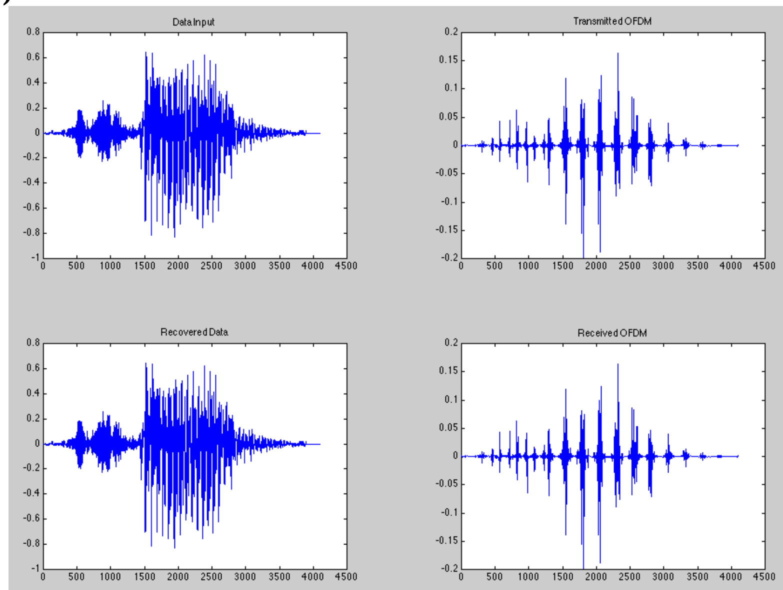

Figure 5: MATLAB Simulation with Sound Input

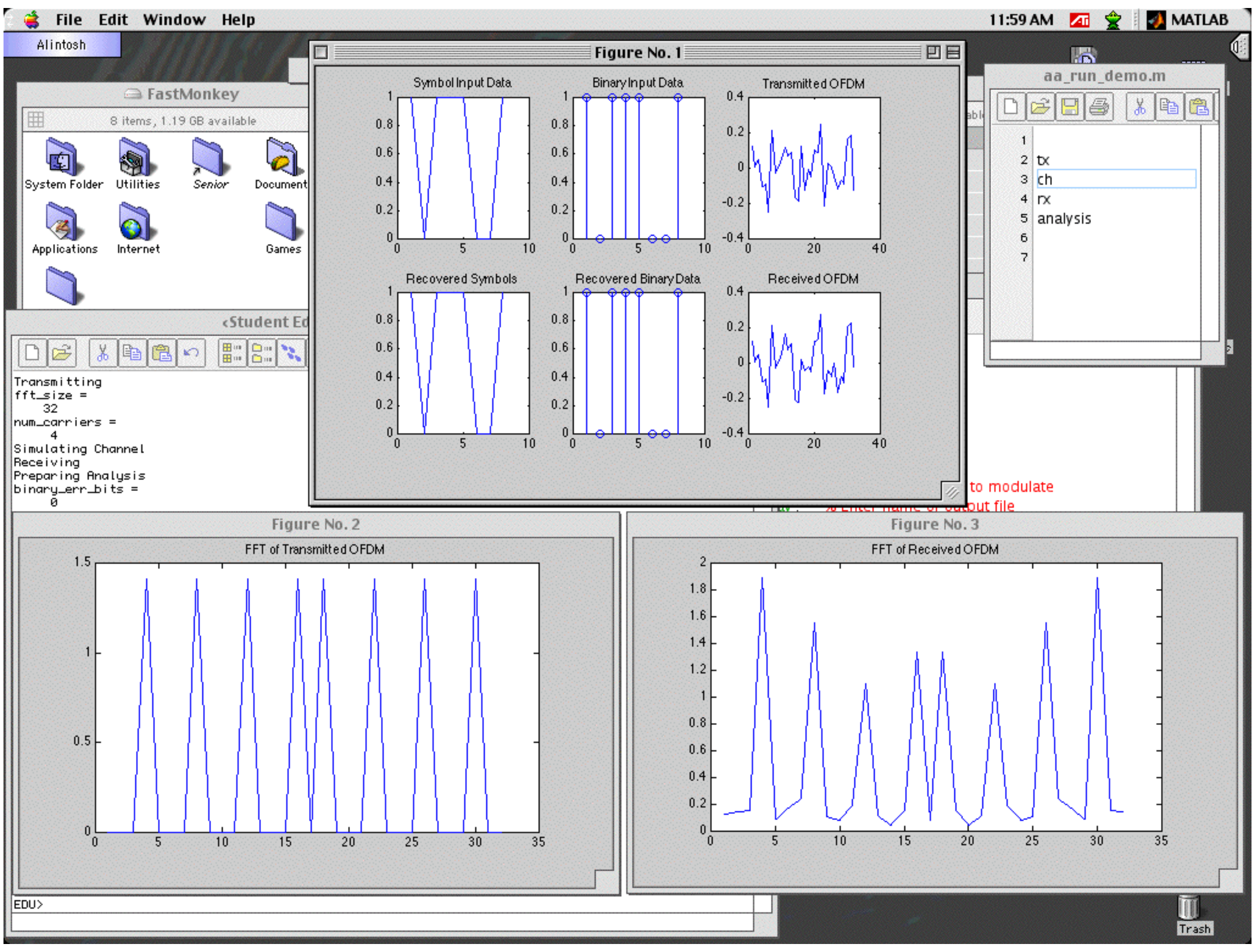

Figure 6: MATLAB Simulation with Multipath Channel