Ultrasonic Communication in Solid Channels using OFDM

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Abstract **– Using an ultrasonic signal for communication is an alternate solution when electromagnetic waves are not feasible for carrying the information through the channel. We can use the ultrasonic signal to conduct communication in different types of media such as solid, liquid, and gas. In this study, we use ultrasound for communication through a metal plate channel. A metal plate is a highly dispersive and frequency selective channel with a severe multipath effect. The OFDM modulation method is customized for the ultrasonic communication channel to enhance communication reliability and reduce the bit error rate. With the channel frequency response, we adaptively map the transmitted information to optimize the selection of subcarriers frequency bands for the highest possible throughput.**

Keywords – Software-Defined Ultrasonic Communication System, Zynq-SoC, OFDM

I. Introduction

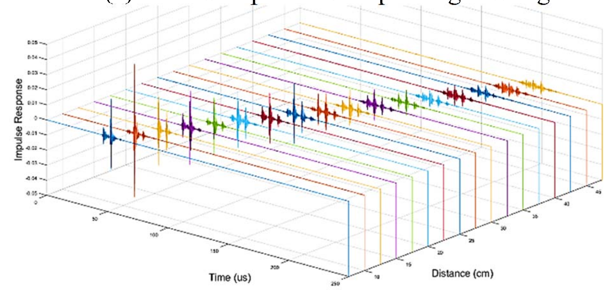
Ultrasonic signal as a carrier for communication is a promising method in certain environments where the transmission of electromagnetic waves is limited. In this paper, we focus on the study of using the ultrasonic signal for communication through solid channels. Compare to liquid and gas channels, ultrasonic communication through solid is more complicated since both longitudinal and transversal waves can propagate in solid [1]. The ultrasonic signal attenuates fast in channels, and it is profoundly affected by the microstructures of the material [2] [3]. The transmitted signal in the channel suffers from reflections, refraction, attenuation, mode conversion before it arrives at the receiver. To conduct the ultrasonic communication experiments, we design a real-time Software-Defined Ultrasonic Communication (SDUC) System [4] [5].

Multipath effects in the solid channels are very severe. With an excitation pulse, the receiver transducer picks up multiple wave packets from the channel, which reduces the Signal-to-Noise Ratio (SNR). These characteristics make the channel very complicated for conducting communication using conventional modulation methods. In this study, customized OFDM communication is designed and deployed on the SDUC system to communicate through solid elastic channels in real-time.

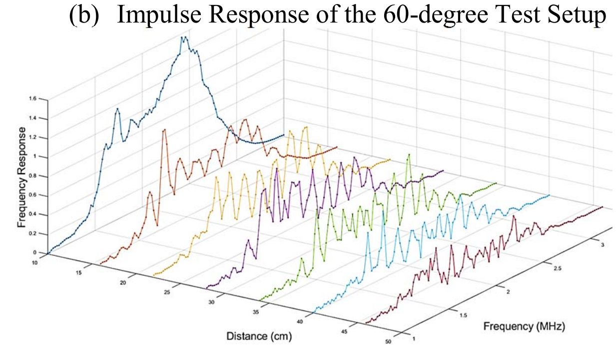
II. Experimental Setup and Channel Analysis

For this study, we design and implement a Software-Defined Ultrasonic Communication (SDUC) platform to conduct an array of ultrasonic communication experiments. A ZYNQ System-on-Chip (SoC) with both ARM A9 processor and FPGA is the central controller and processor of the system. Components such as Digital Down Converter (DDC) and Digital Up Converter (DUC) for signal modulation and demodulation that requires high computation intensity are on FPGA of the ZYNQ SoC. The ARM processor running Linux based operating system transmit and receive the baseband signal to and from the FPGA accelerators. The power amplifier on the transmitter side and the low-noise amplifier on the receiver side can improve the SNR of the communication. The SDUC system can conduct communication in real-time with the support of the FPGA.

(a) Test Setup with Oblique Angle Wedges



(b) Impulse Response of the 60-degree Test Setup



(c) Frequency Spectrum of the 60-degree Test Setup

Figure 1. The plot of Impulse Response and Frequency Spectrum vs. the Channel Distance using Aluminum Plate.

Before we conduct any real-time communication with the SDUC system, we will study the test configuration shown in Figure 1a when two oblique angle wedges are used to transmit and receive the information through a metal plate channel. Figure

1b and Figure 1c show the impulse and frequency response as a function of distance. As confirmed by the frequency and impulse response of the communication channel, the signals are suffering from the multipath effect. The frequency response in Figure 1c is acquired by scanning the channel with the continuous sinusoid wave. It illustrates the frequency selective fading effect in the channel.

Figure 2 shows channel frequency responses plotted against the distance between the transmitter and receiver. This figure demonstrates the frequency selective fading due to the multipath effect.

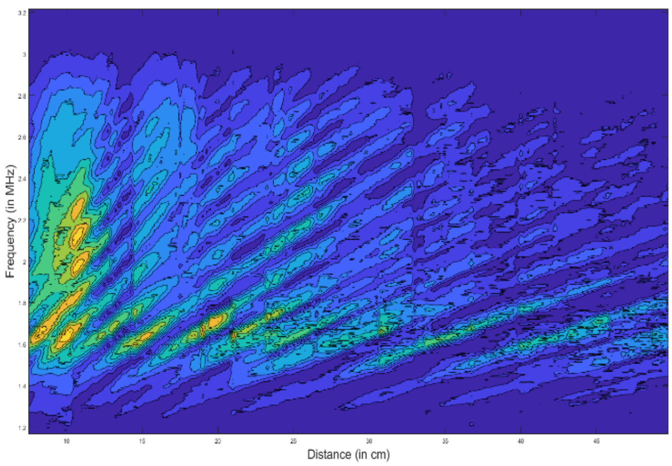


Figure 2. Channel Frequency Response vs. Distance using 60-degree wedges.

III. OFDM FOR ULTRASONIC COMMUNICATION

The OFDM is an efficient communication technique that can transmit more information with the same frequency band usage. In the OFDM communication, the header and payload information are encoded into binary and mapped with QAM or BPSK constellation. IFFT is then applied to each packed 64 complex data to acquire the OFDM symbol. Between each two OFDM symbols, we add a cyclic prefix to separate different OFDM symbols. Digital Up Converter (DUC) modules on the FPGA of the SDUC system upconverts the generated baseband signal to its carrier frequency of 1.8 MHz. The generated digital form of the modulated signal is converted into an analog signal using a 125 MHz high-speed DAC. A power amplifier on the transmitter side and Low Noise Amplifier (LNA) can enhance the SNR. The received signal is sampled and digitized by an ADC operating at 125 MHz. The acquired signal is then passed through a Digital Down Converter (DDC) to acquire the baseband information. After identifying and extracting the OFDM symbols, FFT64 is applied to each received OFDM symbol to recover the time-domain information from its frequency domain sub-carriers. The recovered signal is converted to binary and then decoded into messages.

To demonstrate how ultrasonic communication can benefit from OFDM through the solid channel, we present the test setup in Figure 1a, where the oblique angle wedges are 60 degrees. The distance between the transmitter and receiver is 32 cm. Figure 1b shows the impulse response of the channel, where the observable impulse response lasts for 24 us. The impulse responses at different distances show that communication is suffering from severe Inter Symbol Interference. Figure 1c shows the frequency response of the channel, which reveals the severe frequency selective fading of the channel using ultrasound.

Figure 3 shows the design procedure of the optimized sub-carrier mapping according to the channel frequency response. With the IEEE 802.11a protocol, among 64 frequency bins, 52 are used for subcarriers, which includes 48 data subcarriers and four pilot subcarriers. Figure 3a is the channel frequency response govern by the characteristic of the ultrasonic transducer. The bandwidth of the baseband signal is 500 kHz, and the occupied bandwidth is 414 kHz. We apply a threshold to determine the subcarriers that are highly attenuative and disable them from being used in the communication. Figure 3b shows the optimized OFDM sub-carrier mapping design for this channel.

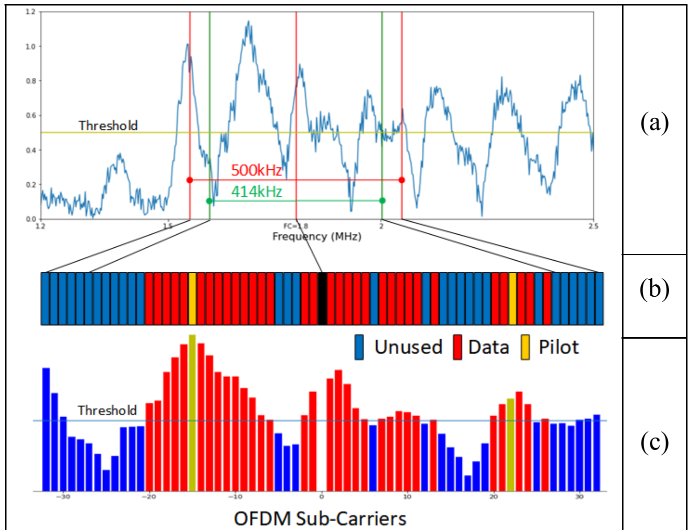


Figure 3. OFDM Sub-Carrier mapping for Ultrasonic Communication

Figure 4 shows the transmitted and received baseband power spectral density in real-time communication on the SDUC platform. The highly attenuated subcarriers marked with green bounding boxes in the frequency domain are not used, which makes the OFDM communication robust and less vulnerable to the multipath effect in ultrasonic communication. With the optimized OFDM subcarrier mapping method, we were able to transmit 200 kbps without any problem through this highly dispersive channel.

Figure 4. OFDM Transmitted and Received Baseband Signal Frequency Response in real-time Ultrasonic Communication on SDUC

IV. CONCLUSION

In conclusion, the ultrasonic wave is a viable carrier signal in the communication. With the SDUC system that we have developed, we can conduct real-time ultrasonic communication through solid channels. In the test configuration, the ultrasonic signal propagates through a 32 cm long solid aluminum bar with oblique angle wedges. Impulse responses and frequency spectrum of channels are adequately studied and analyzed for optimal communication. Using the OFDM technique in ultrasonic communication can offer higher bit rates and lower bit error rates compared to other modulation methods. A lookup table provides an optimized OFDM subcarrier mapping scheme at different channel lengths to combat the multipath effect.

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