Ultrasonic Video Transmission through Solid Metallic Channel

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***Abstract*— Ultrasonic waves are the limited means for wireless communication in solid metallic channels such as metallic bars, plates, or pipes with less attenuation, long-distance propagation, and high detection efficiency. Video monitoring with ultrasonic communication through a solid channel is a promising solution for delivering information through metallic channels. This paper introduces an ultrasonic video communication system through metal bars. However, the key challenges associated with the ultrasonic approach are channel dispersion, distortion, and the multipath effect, which lead to intersymbol interference (ISI). We investigated the feasibility of video stream transmission using the orthogonal frequency-division multiplexing (OFDM) method to reduce the ISI. For this study, an efficient software-defined ultrasonic communication (SDUC) system is designed for video transmission through an aluminum rectangular bar (ARB) channel using two 2.5-MHz ultrasonic piezoelectric transducers with 60° oblique angle wedges. The experimental studies are conducted using ARB channels of 25, 40, and 50 cm long (distance between the transmitter and the receiver). The communication bitrate exceeded 1074 kbps without any error despite dispersion, ISI, and the multipath effect within the ARB channel.**

Keywords—Ultrasonic Communication, SoC Video Transmission, OFDM Modulation

I. INTRODUCTION

Ultrasonic communication through a metallic channel provides a wireless connection between two remote transducers (transmitter and receiver) where the transmission of radio-frequency (RF) or wired signals is inadequate[1][2][3]. In ultrasonic communication, multipath is the ultrasonic wave propagating towards the receiver in different paths. The causes of ultrasonic wave multipath propagation in the solids include reflection from the material boundaries or flaws and other undesirable wave modes. Thus, the multipath effect within the channel causes ISI [4][5][6]. The reverberations generated by the multipath effect highly degrade the signal-to-noise ratio (SNR) and negatively affect communication performance, which makes real-time video transmission very challenging.

In previous research, we utilized time-reversal and pulse-shaping techniques to reduce the impact of reverberations, offering a communication rate of over 10 kbps. [7] [8][9]. In this paper, we examined the feasibility of using orthogonal frequency-division multiplexing (OFDM) to realize intersymbol interference (ISI) mitigation [10][11]. OFDM is robust against multipath and frequency selectivity of the communication channel since it is sensitive to frequency errors in the channel. OFDM is a bandwidth-efficient communication technique with a high data rate and can transmit many orthogonal subcarriers, which are modulated with a different sign. Separate narrowband channels at different frequencies can reduce interference and crosstalk. In addition, a guard band and a cyclic prefix can also mitigate ISI. The payload modulation methods in this work are quadrature amplitude modulations (QAM). A reconfigurable software-defined ultrasonic communication (SDUC) platform is developed to make full use of the aluminum rectangular bar (ARB) channel bandwidth for real-time video transmission [12]. The SDUC consists of a Raspberry Pi for user interface and a Red Pitaya (a reconfigurable and high-performance system-on-chip (SoC)) for transmitting/receiving video streams. The bitrate results will be compared for different distances between the transmitter and the receiver.

This paper is organized as follows. Section II presents the implementation of ultrasonic wave multipath propagation in the ARB channel and OFDM simulation. Section III presents the SDUC system configuration. Section IV presents experimental video transmission results through the ARB channel. Section V summarizes the paper.

II. ULTRASOIC MULTIPATH PROPAGATION IN METALLIC CHANNEL

To exhibit the multipath effect of ultrasonic communication, an experiment is performed by measuring pulse wave response in an ARB channel. The 2.5-MHz PZT transducers combined with 60° oblique angle wedges are used as the transmitter and receiver, and the distance is 40 cm. The transmitted pulse has one µs duration, and the received pulse wave response is shown in Fig. 1a. Ultrasonic beam spreading in the wedges and mode conversion within the bar results in the multipath effect. By extracting the pulses with significant amplitude and delays, the multipath channel model is shown in Fig. 1b, which reveals the eight multipath wavelets.

The multipath channel model represents a realistic multipath effect associated with the ARB channel characteristics. We conduct an OFDM bit error rate (BER) estimation based on the multipath channel model. The QAMs with different modulation schemes are used to modulate/demodulate the binary information. Furthermore, the modulated symbol is transmitted with 2K and 8K subcarriers. Fig. 2 compares the BER performance of different modulation schemes and the number of subcarriers applied in OFDM.

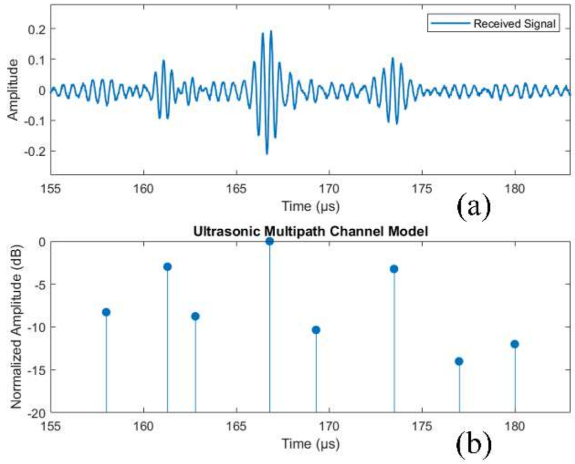

Fig. 1. Ultrasonic multipath channel model. (a). pulse wave response, and (b) multipath channel model.

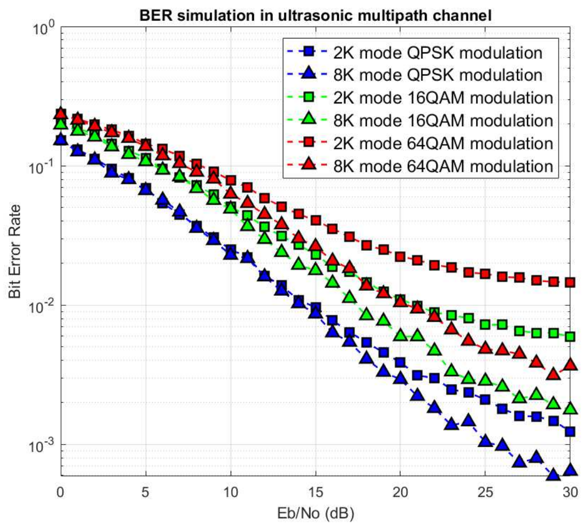

Fig. 2. BER curves estimation using QAMs and subcarriers.

III. SDUC System Configuration

This section presents the major components of SDUC video transmission architecture. The system consists of a single-board Raspberry Pi computer, and the video stream is transmitted/received using a reconfigurable system-on-chip (SoC) Red Pitaya platform. Both devices are low-cost, low-form factor, scalable, and power-efficient modules. Consequently, the transmitter and receiver units are supported by batteries, resulting in low-cost installation and a system suitable for applications in different settings with limited power accessibility. In addition, the system can also interface with a variety of wired or wireless application environments.

Fig. 3 displays the real-time ultrasonic video transmission and reception architecture through an ARB channel using the SDUC platform. The raw video stream is acquired from the webcam, and the Raspberry Pi is used to compress, format, and packetize the video data. The Red Pitaya platform emits the packetized video streams for ultrasonic transmission through an ARB channel using a PZT ultrasonic transducer. On the receiver side, a PZT receiver detects the ultrasonic signal, and the Red Pitaya platform and Raspberry Pi are used to acquire the OFDM data stream and recover the video stream. In the end, the Raspberry Pi will access the Internet through a wireless router and deliver the video stream to the remote users by the content delivery network (CDN) server.

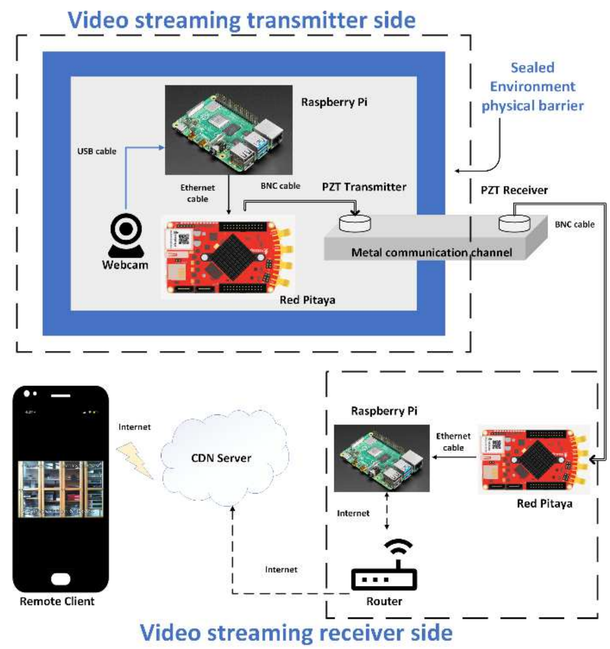

Fig. 3. SUDC system configuration

IV. Experimental Test Results

Bitrate in ultrasonic communication defines the number of bits that can be transferred within a certain time. An ultrasonic communication with a high bitrate makes real-time video transmission through the solid metallic channel practical. However, due to the limited bandwidth of the ARB channel, a high bitrate leads to a lower SNR and, consequently, a higher BER of video transmission. Ultrasonic video transmission using the SDUC platform was performed to evaluate the highest possible transmission rate in an ARB channel.

The experiment is performed by transmitting a 720p video stream through the ARB channel over 25 cm. The received and recovered video frames are shown in Fig. 4, with resolutions of 1280×720. We calculate the end-to-end BER by comparing the recovered video frames with the original transmitted frames. Note that channel coding and modulation are considered. For a 25-cm-long channel, we implement a symbol rate of 250k SPS and 64-QAM modulation to achieve a high-quality real-time video transmission with a bitrate of 1 Mbps and BER of 3.3 $\times 10^{-4}$.

We combined the impact of six symbol rate settings (20k, 50k, 100k, 250k, 500k, and 1250k symbols per second) for efficient and reliable video transmission and three QAM modulation orders to find the optimal bitrate for video transmission. We examined all the results for channel lengths of

25, 40, and 50 cm presented in Table I, the optimal bitrate for a channel length of 25 cm uses 64-QAM modulation and a symbol rate of 250k SPS. This arrangement allows a maximum bitrate of 1074 kbps. Similarly, the optimal bitrate for a channel length of 40 cm uses QPSK modulation and a symbol rate of 250k SPS. This arrangement allows a maximum bitrate of 358 kbps. The optimal bitrate for a channel length of 50 cm uses QPSK modulation and a symbol rate of 50k SPS. This arrangement allows a maximum bitrate of 72 kbps.

TABLE I
Optimal Bitrate For Channels Length Of 25, 40, And 50 cm

Channel Length	QPSK	16-QAM	64-QAM
25 cm	716 kbps (500k SPS)	716 kbps (250k SPS)	1074 kbps (250k SPS)
40 cm	358 kbps (250k SPS)	143 kbps (50k SPS)	N/A
50 cm	72 kbps (50k SPS)	57 kbps (20k SPS)	N/A

Fig. 4. OFDM constellation diagram using 250k and 500kSPS

V. Conclusion

In this paper, we discussed the feasibility of applying the OFDM ultrasonic communication through the ARB channel. The proposed OFDM communication protocol can overcome the multipath and reverberations and achieve video transmission in the ARB channel. The data analysis is conducted by using the FPGA-based SDUC platform. Two 2.5 MHz PZT ultrasonic transducers are utilized as the transmitter and receiver. The ultrasonic video transmission can be achieved over 1 Mbps bitrate.

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