

Experimental Comparison of Digital Beamforming Interference Cancellation Algorithms using a Software Defined Radio Array

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Abstract—Digital beamforming (DBF) is the holy grail of antenna array technology. However, very few DBF arrays have been demonstrated due to the high cost of implementation. Here we report on a cost-effective platform for DBF using a software-defined radio array and present experimental results on interference cancellation using the DBF platform. We transmitted digital data modulated with 4-QAM from a single-element transmitter to the 4-element DBF array while a single-element interferer disrupted the transmission. Digital beamforming interference cancellation was then implemented with three different algorithms, namely, least mean squares, sample matrix inversion, and recursive least squares. The bit error rates in each case are compared for several interference power levels. The results indicate that all adaptive methods provide significant improvements over unit weights, with sample matrix inversion outperforming recursive least squares and recursive least squares outperforming least mean squares.

Keywords—digital beamforming, least mean squares, sample matrix inversion, recursive least squares, software defined radio

I. INTRODUCTION

The rapid growth of wireless communication infrastructure has created an environment where multiple devices need to communicate with each other simultaneously. In these scenarios, unwanted signals will be received by unintended receivers in the same channel. These interferences degrade the signal-to-noise ratio (SNR) and disrupt communication, creating a need to cancel interference in modern communication devices and systems [1]. In order to improve the SNR, adaptive nulling interference cancellation methods place array pattern nulls in the direction of interference, thus improving the SNR. DBF arrays convert an analog signal into digital values that are weighted by an algorithm to reject interference with minimal disruption to the desired signal. The challenge is that DBF arrays are costly since they require a complete transceiver at each element of the array [2-4].

In this paper, we report on the interference cancellation capability of a DBF array which uses software defined radios (SDRs) at each element [5-7]. We outline the hardware implementation of the system and then present experimental results on interference cancellation with the developed testbed.

Digital data were transmitted from a single element transmitter to a 4-element antenna array using 4-QAM while an interferer disrupted the signal. Least mean squares (LMS), recursive least squares (RLS), and sample matrix inversion (SMI) algorithms were implemented and their bit error rates were studied as functions of the interferer output power. We show that this low-cost DBF testbed is a suitable candidate for interference cancellation in modern communication systems.

II. EXPERIMENTAL SETUP OF THE BEAMFORMING HARDWARE

Our experimental setup consists of a four-element receiver array, a single-element transmitter, and an interference source. The transmitter is an NI USRP-2922 placed directly in front of the receiver, and the interferer is a Signal Hound VSG25A placed about 45 degrees from the front of the receiver. The signal is received by the four-element array, which is implemented with four NI USRP-2922 SDRs with a CDA-2990 clock to synchronize the RF and sample clocks in each NI USRP. Although the clock frequencies are aligned, the measured phases and amplitudes at each antenna are different. Additionally, the sample clocks at each device are offset by several samples. A software calibration algorithm using the transmitter and receiver corrects any offsets between antennas. Each device is controlled independently by a central computer. A schematic of this setup is shown in Fig. 1.

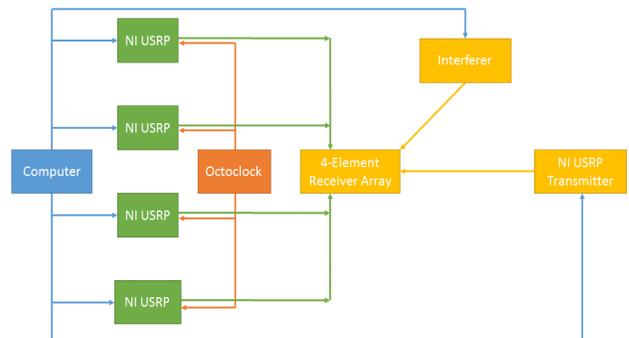


Fig. 1. Block diagram of the hardware setup for the receiver array, transmitter, and interferer.

The program used by the receiver to record data initially controls both the receiver and transmitter to calibrate the antenna array, then disconnects from the transmitter. Data from the receiver are then recorded and analyzed continuously to allow evaluation of the array calibration and SMI, LMS, and RLS performance. When a digital signal is recorded, the program converts the signal to binary data and a constellation plot. The setup can write the recorded data to an ASCII file, a binary file, and uncompressed image or audio files. QAM, PAM, and PSK digital modulation schemes can be used and compared, and beamforming weights can be generated with multiple beamforming algorithms.

III. EXPERIMENTAL STUDIES ON INTERFERENCE CANCELLATION

The array weights were determined before the digital data transmission using a pilot signal from the transmitter while the interferer transmitted at 0 dBm. To prevent phase drift from interfering with the weight calculations, the algorithms used only the magnitude of the received signal at each antenna. While this corrected issues from phase drift, it eliminated phase information from the signal and may impact the performance of the algorithms. The transmitter sent random binary data to the receiver using 4-QAM, and the receiver interpreted the signal using unit weights and weights from the LMS, SMI, and RLS algorithms. Bit error rates were calculated for each case as a function of the interferer power level. 24 trials were recorded, with each trial recording bit error rates for interferer power levels from -6 to 13 dBm. The interferer was repositioned between each trial to prevent its specific position from impacting the experiment. The mean bit error rates are given in Table I. Standard deviations are not included in the table since the bit error rates from the trials are concentrated around 0% and 50%, resulting in large and uninformative standard deviations.

TABLE I. MEAN BIT ERROR RATES

Interferer Power	Algorithm			
	None	LMS	SMI	RLS
-6 dBm	4%	0%	2%	4%
-3 dBm	4%	1%	2%	4%
0 dBm	16%	16%	2%	4%
3 dBm	30%	15%	4%	6%
6 dBm	36%	22%	4%	10%
9 dBm	46%	27%	13%	19%
13 dBm	44%	25%	15%	17%

The results show that each beamforming method provides a significant improvement over unit weights. SMI outperforms LMS and RLS, and RLS outperforms LMS. LMS appears to outperform the other methods at low interference levels, but this may be a product of the sample size. Fig. 2 shows the constellation plots for a case with the interferer transmitting at 13 dBm. In this case, unit weights produced an approximately 49.7% bit error rate while all beamforming algorithms received data without errors.

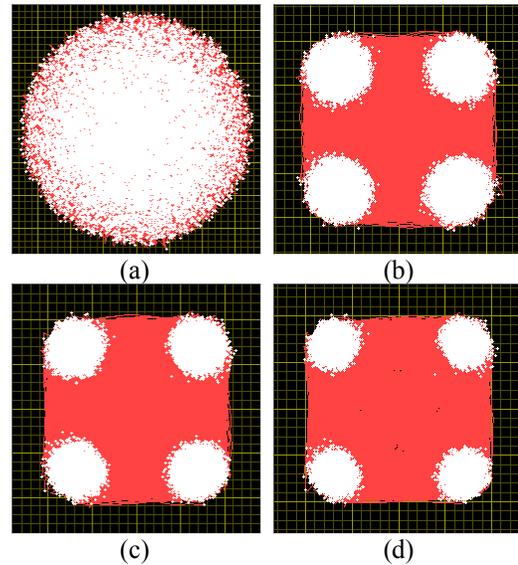


Fig. 2. Constellation plots for the 4-QAM signal received by the beamformer with 13 dBm interference and different algorithms: (a) none, (b) LMS, (c) RLS (d) SMI.

IV. CONCLUSION

We present a low-cost platform for digital beamforming using a software defined radio array. We report on the experimental setup of the hardware system, and then use the testbed to evaluate and compare the performance of LMS, SMI, and RLS interference cancellation beamforming methods. Using a single-element transmitter, we sent 4-QAM digital data to the 4-element DBF array while an interferer produced a signal to disrupt the transmission. The results show that the LMS, SMI, and RLS algorithms each provide a significant reduction in bit error rates when compared with unit weights. The SMI algorithm outperforms RLS, and RLS outperforms LMS.

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