Adaptive Wireless Communication Systems using Software-Defined Radio Arrays

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***Abstract*—This paper summarizes the outcomes of research that was partially supported by the 2019 IEEE MTT-S Graduate Fellowship Award. The main results are the demonstration of a software-defined radio array and experimental demonstrations of novel interference cancellation methods for adaptive antenna arrays. The experiments show that, in the event of a non-negligible carrier offset between a receiving antenna array and a transmitting device, the novel interference cancellation methods presented here outperform classical interference cancellation approaches.**

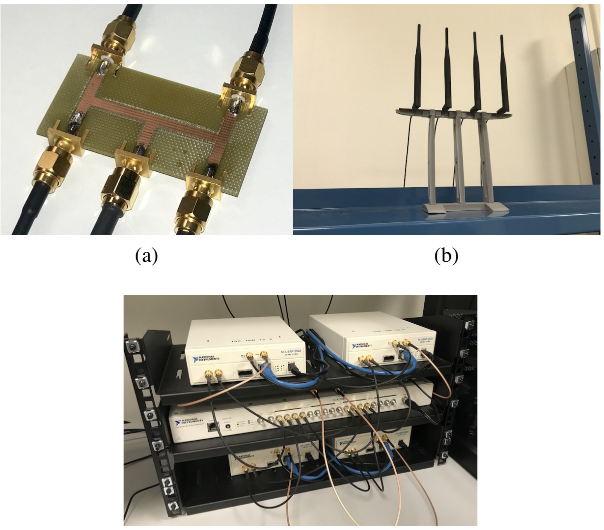
***Index Terms*—adaptive beamforming, software-defined radio, interference cancellation**

I. INTRODUCTION

WIRELESS devices are increasing in number and density, causing more devices to operate in close proximity on shared frequency allocations. This will increase interference between devices, reducing wireless throughput. One means of avoiding a potential disruption of wireless networks is adaptive interference cancellation using adaptive antenna arrays. This work focuses on an experimental demonstration of novel interference cancellation methods using a software-defined radio (SDR) array setup. SDR arrays are low-cost setups that enable the use of digital signal processing (DSP) for implementing radio functions [1], making them ideal for experimental studies on new array processing algorithms.

II. SDR ARRAY SETUP

The SDR array presented here uses a 2.45 GHz four-element uniform linear array with half-wavelength element spacing and a National Instruments (NI) USRP-2922 at each element. SDR arrays require synchronization so the SDRs all act as a single device. Sample times and local oscillator (LO) frequencies can be aligned using a commercial clock distribution accessory, such as an octoclock, which in this case is an NI CDA-2990. Phase calibration is an additional requirement. The LO phases cannot easily be aligned in hardware, so a common practice is to measure the reported phases when a reference signal is inputted to the SDRs and correct the measured phase offsets in software. The reference signal can be supplied using an RF switch that allows the SDRs to switch between the antenna elements and a reference signal [2], using a plane wave from a distant transmitter [3], or using a constant reference signal that can be distinguished from incident signals using DSP [4]. In our array, each SDR has a built-in RF switch that allows it to switch between an antenna and the reference signal. A reference signal is supplied to each SDR using a Signal Hound VSG25A signal generator and a four-way power divider. The power divider was designed and manufactured in-house using three microstrip T-junctions. The power divider, SDR hardware setup, and the antenna array is shown in Fig. 1.


(a) (b)

(c)

Fig. 1. Software-defined radio array hardware: (a) the power divider used for phase calibration, (b) a 2.45 GHz antenna array, and (c) a rackmount with the SDRs and synchronization hardware

III. ADAPTIVE INTERFERENCE CANCELLATION

The output from an antenna array is often a weighted sum of the signals from each array element. The complex weights adjust the amplitude and phase of the signals from each array element. This can be written as

$$\vec{y} = X\vec{w}, \tag{1}$$

where y_n is the output of the array at sample n, $\vec{w}$ is the array weighting vector, and X_{nm} is the received signal from element m at sample n.

Adaptive interference cancellation algorithms compare the received data, X to an expected signal, $\vec{d}$ to isolate the signal from interference, usually picking a weighting vector $\vec{w}$ so the output $\vec{y}$ is close to an expected signal $\vec{d}$. Sample Matrix Inversion (SMI) is generally the most effective classical algorithm [5], using a pseudoinverse to obtain

$$\vec{w} = X^{+}\vec{d}, \tag{2}$$

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where X^+ is the pseudoinverse of X [6]. The pseudoinverse minimizes $\left\|\vec{d} - X\vec{w}\right\|_2$, where $\|\cdot\|_2$ is the Euclidean norm.

An issue is the carrier offset, or the difference in the LO frequencies of the transmitter and receiver. This causes a progressive change in the phase measured at each time sample. SMI works well when the carrier offset is negligible, but it otherwise prevents reception of the intended signal [6]. To work successfully, SMI requires the carrier offset to be removed, which can be done if the carrier offset is known. In cases with high interference, however, it may not be easy to measure the carrier offset without interference cancellation.

A simple solution we proposed in [6] is to ignore the phase in the signal, replacing X with $|X|$, where $|\cdot|$ is the element-wise modulus of the argument. When solved with SMI, this can be called amplitude-only SMI (AOSMI). The resulting element weights will weight only amplitudes and not phases, however, making this approach dependent on multipath effects that produce different signal and interference amplitudes at each array element.

Another approach is to minimize a different cost function than that minimized by the pseudoinverse. A cost function proposed in [6] is

$$\text{cost} = \left\|\vec{d} - \left|X^H\vec{w}\right|\right\|_\infty , \qquad (3)$$

where $\|\cdot\|_\infty$ is the l_∞ norm, which returns the magnitude of the largest vector element. This cost function is difficult to minimize analytically but can be minimized using numeric optimization methods such as genetic algorithms. This method will be referred to as the genetic algorithm (GA) approach.

IV. EXPERIMENTAL DEMONSTRATION

SMI, AOSMI, and GA were compared using the SDR array in a lab with one transmitter and one interference source. Signal to interference plus noise ratio (SINR) measurements were performed using the lab setup for a sweep over interference power levels for a case with the transmitter synchronized with the antenna array, which eliminated any carrier offset, and a case with the transmitter unsynchronized with the array, meaning a small carrier offset was present. Synchronization of the transmitter with the array is achieved by connecting the transmitter to the array octoclock using coaxial cables. Results were averaged over 16 trials. All devices were periodically repositioned between trials to prevent multipath effects associated with a specific position from affecting the results. The resulting SINR measurements are shown in Fig. 2. GA always outperforms AOSMI. When the transmitter is synchronized to the array octoclock, SMI outperforms GA and AOSMI. When the transmitter is not synchronized to the octoclock, however, GA and AOSMI both outperform SMI.

V. CONCLUSION

We demonstrated an SDR array platform for a four-element array. The SDR array was used to demonstrate novel interference cancellation methods, finding that novel approaches can outperform classical interference cancellation methods in cases with non-negligible carrier offsets. Further research would likely involve funding improvements over the interference cancellation methods presented here.

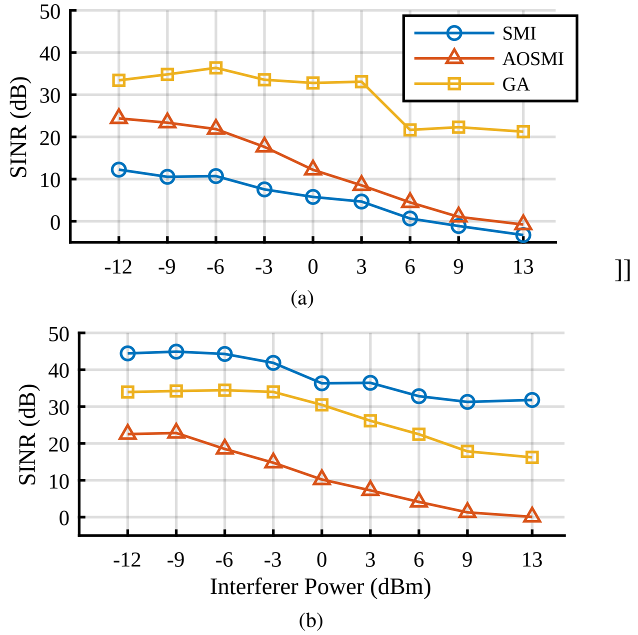

Fig. 2. Plots of SINR versus the interferer power setting for SMI, AOSMI, and GA: (a) transmitter unsynchronized with the array and (b) transmitter synchronized with the array.

VI. FELLOWSHIP IMPACT AND CAREER PLANS

Following this research, I intend to work with signal processing in industry. I have plans to pursue a PhD after several years of industry experience.

The MTT-S Graduate Fellowship Award has improved my confidence in writing grants, encouraging me to pursue a PhD. It has also helped me understand academic research and provided financial support for my MS degree. I am grateful and honored to have received this opportunity.

Attending International Microwave Symposium 2019 exposed me to current industry work and encouraged me to pursue a career in industry. Seeing conference presentations on relevant topics helped me understand current RF research.

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