**WAN-Based Locating and Beamforming**

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**Introduction**

Beamforming is the modern technique of using signal delays across an array of antennas to determine the direction of arrival for a signal used in 5G communications. One major advantage of beamforming is its ability to both determine the direction of arrival, and then use this direction of arrival to boost signal strength in the transmitter in that direction. Furthermore, a single antenna array can be optimized to receive a signal in any direction
eliminating the need for multiple antennas with different orientations or moving the antennas, depending on the signal location.

In this project, a beamforming receiver is constructed to determine the direction of arrival of a 915MHz signal for the purposes of creating a secure channel with low loss from terrain interference. Our system determines the phase delay on each element in an array and implements an algorithm capable of phase shifting each antenna element in the array in order to allow for constructive interference at the receiver. The receiver was built using 4 antennas mounted on 3D printed stands and arranged in a square formation, attached to a Kerberos SDR. The SDR IQ samples are used in the beamforming algorithm implemented in MATLAB Simulink.

**Methodology**

Our beamforming receiver began its development with the consideration that it would operate within the 915MHz ISM band. A patch array was studied, simulated, and chosen in our design for its prevalence in 5G networks, low cost, and ease of manufacturing.

Considering the cost, manufacturing time, and lack of lab testing equipment, we decided make use of the Abracon APAE915R2540ABDB1-T 915MHz patch antenna. Four of the antennas were inserted into custom 3D printed stands with flange SMA connectors attached to the stands. Epoxy was used to hold the patch antennas to the 3D printed stands and the SMA flanges to the stands.

The system was designed to operate over four independent channels, each with a dedicated antenna. Each channel would need to be able to take fully phase- and frequency-coherent collections. The KerberosSDR (a 4-channel SDR platform based on the mass-produced RTL-SDR dongles) was selected to perform this task.

A system simulator was built using MatLab Simulink software. This simulator was used as a test bed for the direction-finding and beamforming algorithms. It uses a near-continuous AM time signal that is time-delayed based on its position relative to the receiver. The signal then goes through a analog-to-digital converter and dowconverter before being put into a buffer for the algorithms to ingest.

The primary algorithm tested was a delay-and-sum beamformer. By calculated the time and phase difference between channels, the angle-of-arrival can be determined. The subsequent signals can be delayed and summed together to receive a higher SNR signal. The expected gain is $10\log(4) = 6.026$ dB.

The power spectrum of the original four channels is shown below. The SNR without beamforming is approximately 33 dB. With Beamforming, the SNR increased to 39 dB. The plot on the left shows the raw signal and the plot on the right shows the beamformed.

**Results**

Once the model is running, the angle of arrival is continually estimated with the presence of Gaussian noise, leading to a distribution around the actual angle. A plot showing the estimates relative to the actual location is shown.

The angle difference from the simulated signal's location estimation was typically within 0.14 degrees of the signal with a standard deviation of 0.092.

[Image of raw and beamformed spectra]

**Future Work**

With future work, the physical system could be made to output fully coherent collects to do angle of arrival estimations. With a second base station, the system could net a greater gain and an exact physical location of the transmitter.

**Summary**

By taking advantage of spatial diversity, a myriad of different options open up. Using a 4-channel receiver, the angle-of-arrival of signals was calculated, allowing for the estimation of the location of a transmitter. The received SNR can also be improved. This offers up to 6 dB of gain without the added cost of expensive LNAs.

**Key References**

1.86658834.160181816-187852901.1601381816


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