Experimental Demonstration of Distributed Beamforming on Two Flying Mini-Drones

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***Abstract*—Combing distributed small wireless systems on mobile platforms such as swarm airborne mini-drones has been explored recently. Localization and synchronization of the mobile drones are the main challenges limiting its practical applications. In this paper, we proposed a new approach to circumvent this limits by considering the drones as relay nodes, where the received signals are modulated to different frequencies and then re-transmitted to the final receiver for demodulation and beamforming. Real-time adaptive beamformer algorithm is used to compensate for the phase delay difference among drone elements in RF circuitry and in propagation paths caused by different drone elements positions. A beamforming array based on two-drones uses to demonstrate this concept. Improved signal to noise ratio (SNR) has been experimentally demonstrated with such beamforming approach. The proposed beamforming system architecture is expected to extend to a large of number distributed mini-drones for future wireless sensing and communication systems.**

***Index Terms*—swarm drones, swarm aperture, beamforming arrays, phased arrays, adaptive beamformer.**

I. Introduction

As the steady improvement of battery technology [1], swarm mini-drones with their increasing endurance time have gain enormous amount of interest for many applications in the recent years. Their potential of serving as mobile platforms for integration of high performance, low power analogue and digital circuits opens up great opportunities for distributed and collaborative sensing and communications [2].

For a beamforming array, coherent combination of element output signals requires each channel of the array being applied with precise phase delay and amplitude attenuation. Array element positions information, i.e., localization, and accurate synchronizations between each array channels are required for coherent beamforming [3][4]. For a traditional beamforming array based on solid aperture, localization of fixed antenna elements position and synchronization of wire connected array channels can be easily implemented. For the beamforming array based on swarm aperture, however, the fast moving elements and the wireless linked channels make it difficult for localization and synchronization of the swarm drone elements.

In this paper, a new system architecture is proposed to circumvent the localization and synchronization limits for swarm elements. We leverage on the closed loop feature in communication links to compensate for the errors in the physical layer. We develop the RF hardware of the swarm repeater nodes and demonstrate end-to-end communications with these repeater nodes. The localization and synchronization issues are no longer a fundamental limits in the proposed approach as they will be automatically taken care with the adaptive digital signal processing by using frequency diversity transmission techniques between the drones and the final receiver.

To prove the system concept, a beamforming array based on two mini-drones without considering the localization and synchronization of drone elements are experimentally demonstrated. In the test system setup, the received signal in each drone are amplified and modulated to different frequencies. The re-transmitted signals from the drones are received by the final receiver for demodulation and digital beamforming. The phase difference due to the time delay in circuitries and propagation path difference of elements can be compensated by the real-time beamforming algorithm.

II. System Concept

For a beamforming array based on swarm drones, the quick motion of the platforms and the missing of wired links make the localization and synchronization of the swarm elements extremely difficult. Phase errors of the beamforming weights should be as accurate as a fraction of RF cycle time to avoid losing the coherence in RF power combing at the receiver.

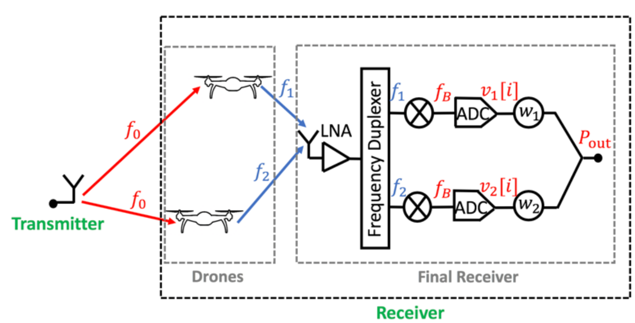

Fig. 1 System architecture for a beamforming array system on two mini-drones.

Fig. 1 shows the proposed system architecture for an array based on frequency diversity beamformer technique to circumvent the localization and synchronization issues. The received signals at the swarm drones are amplified and sent out at different frequencies from the receiving signal frequency f_0. The re-transmitted signals from the drones are received by the final receiver through a broadband antenna, demultiplexed to N different channels by a frequency multiplexer, downconverted to the same baseband frequency f_B, and digitized by ADCs. Beamforming coefficients are applied to the baseband signals on each channel for SNR improvement.

III. Measurement

From the system link gain analysis in our previous work [5], the path loss between the drones and the final receiver can be overcome by increasing the gain of the relays on the drones. By assuming that the transmitter is far away from the drones, required relay gain is about 55 dB when the distance between the drone and the final receiver is 10 meters, which is within a reasonable level for practical applications.

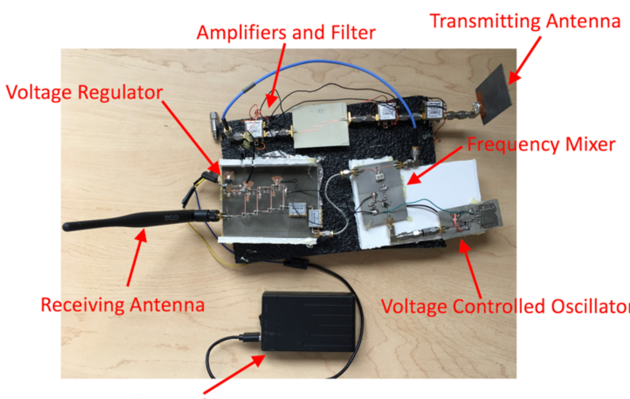

Fig. 2 Relay circuits carried by drones

The relay for each drone consists of receiving and transmitting antennas, LNAs, bandpass filter, frequency mixer, high power amplifiers. The local oscillator signal is generated by a Voltage Controlled Oscillator (VCO) and the DC power is supplied by an external battery, the stability of the voltage of which is controlled by a voltage regulator. The measured relay gain is about 60 dB. For the final receiver, two Universal Software Radio Peripherals (USRPs) are used to mix and sample the signal for each channel. The sampled digital data from USRPs are exported to MATLAB for real-time post-processing.

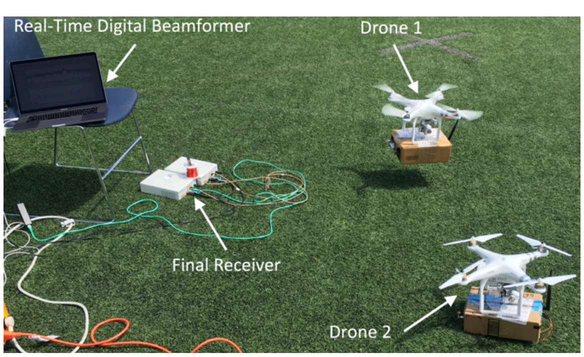

Fig. 3 Test system setup for beamforming array on two mini-drones

The experimental test result in real-time is shown in Fig. 4. Appling the adaptive digital beamformer to the based band signals $v[i]$, the output SNR at the final receiver is always higher than for each channel. When the SNRs of the drone elements are closed, the array output SNR is increased by about 3dB. When the SNRs of the two drone elements are different, the array output SNR is closed to the drone element with higher SNR. These test results agree well with the expected theoretical results.

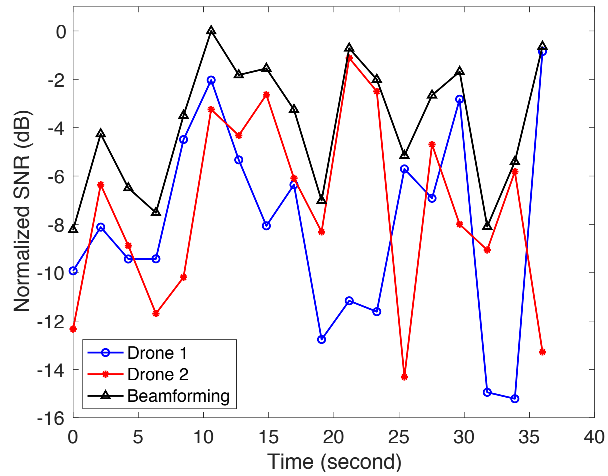

Fig. 4 Test output SNR at the final receiver with real-time adaptive beamforming.

IV. Conclusion

A beamforming array based on two min-drones with random positions is experimentally demonstrated by the system output SNR improvement. Applying the adaptive beamforming algorithm, the measured array output SNR is about 3 dB higher than the individual drone elements, which agrees well with the theoretical result. The proposed approach in this paper could effectively address the localization and synchronization limits of swarm drone elements, which provides an opportunity for developing an entirely new paradigm for future wireless system.

References

[1] J. W. Choi, and D. Aurbach. "Promise and reality of post-lithium-ion batteries with high energy densities." *Nature Reviews Materials,* vol. 1, No. 4, pp. 16013, 2016.

[2] J. A. Nanzer, et al. "Open-loop coherent distributed arrays." *IEEE Transactions on Microwave Theory and Techniques,* vol. 65, no.5, pp. 1662-1672, 2017.

[3] J. Diao, J. W. Kunzler, and K. F. Warnick. "Sidelobe Level and Aperture Efficiency Optimization for Tiled Aperiodic Array Antennas." *IEEE Transactions on Antennas and Propagation,* vol. 65, no. 12, pp.7083-7090, 2017.

[4] J. Diao, and K. F. Warnick. "On the bandwidth gap between the array-feed and cluster-feed regimes for broadband multifeed systems." *IEEE Transactions on Antennas and Propagation,* vol. 64, no. 6, pp. 2207-2216, 2016.

[5] J. Diao, M. Hedayati, Y. Huang, and Yunxuan E. Wang. "Adaptive wireless beamforming for swarm array." In *URSI National Radio Science Meeting (USNC-URSI NRSM), 2018 United States National Committee of*, pp. 1-2. IEEE, 2018.