Adaptive Wireless Beamforming for Swarm Array

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***Abstract*—In this paper, we present a novel adaptive wireless beamforming technique for swarm array (SA). The array elements are airborne self-organized mini-drones that act as RF repeaters between the target and the designation. The repeaters amplify and up convert the received signal and transmit to the destination at slight different frequencies among them to avoid self-interference. The receiver will separate the mixed signal to each RF channel through a filter bank, down convert to baseband, amplified, digitized and send to a PC or FPGA based beamformer to recover the desired signal. System principles, simulation study on link budget and SA noise model, and the repeater design are presented.**

I. INTRODUCTION

Utilize mobile platforms such as a swarm of airborne mini-drones for sensing and communications has recently emerged as a critical technology [1-5]. Swarm array (SA) may enable applications such as unmanned industry control and inspection in scenarios that are unsafe for human beings including the monitoring of chemical manufacturing process or inspection of nuclear plants. They can also be used in construction of a "smart city" as information gateways for the Internet of Things (IoT) or for airport security and anti-terrorism inspection, for vast scale applications such as agriculture monitoring, drug control and environmental inspection and control. Swarm array can be set up as emergency telecommunication infrastructure after disaster or as an assistant to GPS based systems in providing wireless localization.

Adaptive array beamforming technique that relies on training sequences to search for the optimal complex weighting coefficients has been well developed for communication, sensing, radar, sonar and radio astronomy applications [6]. Many sophisticated adaptive array processing algorithms are used to continuously distinguish among the desired signal and interferences and form an unlimited number of beam patterns to optimally improve signal strength and suppress interferences.

We propose to use adaptive array beamforming for SA communications. Since hard wire connection does not exist for SA to the beamformer, the SA elements will be designed as relay nodes, wirelessly sending channel signals to the destination for processing.

II. SYSTEM OVERVIEW

The schematic of the adaptive wireless beamforming system for swarm array is shown in Fig. 1. The system consists of *N* mobile repeaters that receive signal from a target and send out element signals at slightly different frequencies to avoid self-interference. The receiver consists of a UWB antenna and a standard Frequency Division Multiple Access (FDMA) receiver that demultiplexed the multi-frequency signals, down convert to base band, digitize for digital beamforming. When transmitter sends out training sequences, adaptive beamforming algorithms may be applied at the final receiver [6] to automatically calibrate the phase error due to the position and motion of the drones.

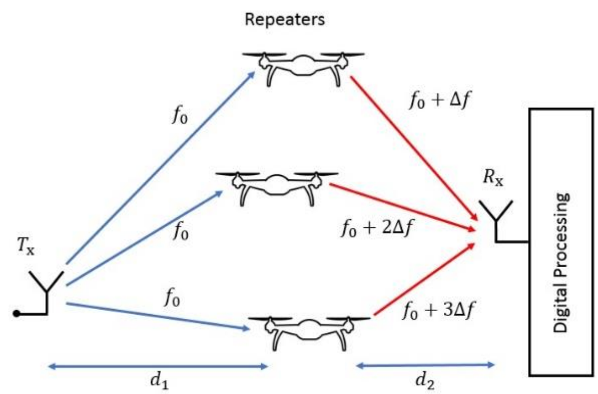

Fig. 1. Wireless adaptive swarm array beamforming system diagram.

III. LINK BUDGET ANALYSIS

Matlab simulations were carried out for SA relay link analysis and SA system noise modeling. Some assumptions have been made for our study:

- The transmitted signal is a narrow band communication signal at 2.4 GHz.
- The distance between transmitter and receiver is 1 km.
- The repeater signals are at 2.6GHz, 2.8 GHz and up.
- Doppler frequency shift is ignored due to low speed of mini-drone (typical < 4m/s).
- Multipath and interference are ignored.

The normalized available power on receiver from one repeater is shown in Fig. 2.

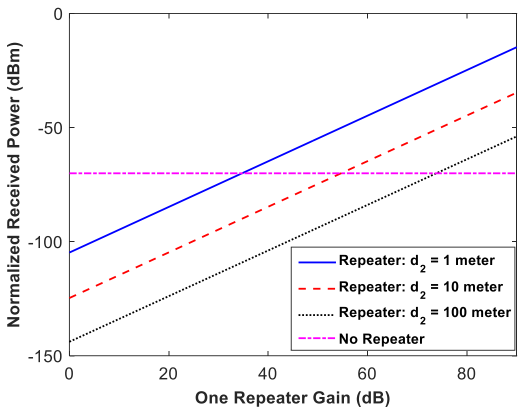

Fig. 2. Normalized receiving power over repeater gain for different distances between the repeater and the final receiver.

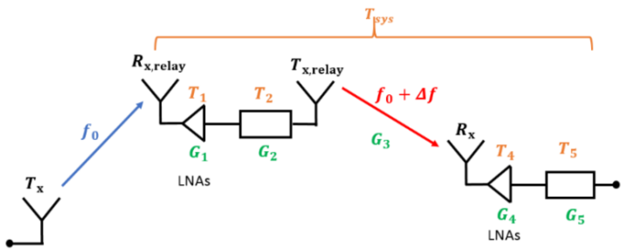

Fig. 3. System noise model.

The antenna gain of transmitter is 20 dB and the operation frequency f_0 is 2.4 GHz. The antenna gain for repeaters and receiver is 3 dB. Received power can be enhanced by increasing the repeater gain and reducing the distance between the repeater and receiver. Compared to the case of the absent of repeaters, the received power can be largely increased by using high-gain repeaters.

The system architecture for thermal noise is shown in Fig. 3. Based on the figure, system noise temperature can be written as,

$$T_{sys} = T_s + T_1 + \frac{T_2}{G_1} + \frac{T_s}{G_1 G_2} + \frac{T_4}{G_1 G_2 G_3} + \frac{T_5}{G_1 G_2 G_3 G_4}, \quad (1)$$

where T_s is external noise temperature including ground and sky thermal noise, T_i (i=1,…,5) is thermal noise, and G_i (i=1,…,5) is the gain for each part. G_3 is path loss from repeater to receiver, G_2 is the gain composed of mixer and bandpass filter and G_5 is receiver gain after LNA. In the absent of repeaters, the system noise temperature become

$$T_{sys} = T_s + T_4 + \frac{T_5}{G_4}. \quad (2)$$

The noise figure impact is minimum, for example, if the relay noise figure is 3dB and 60dB gain, the received power at the receiver is 15dB higher than without relay, but the noise figure in the end will be only 1.2 dB worse.

IV. Repeater Design

Fig. 4 illustrates the block diagram for our repeater design. The repeater amplifies the received signal using a set of sequentially connected low noise amplifiers (LNA). The required LNAs gain and noise figure can be calculated from Fig. 2 and (1), respectively. A narrow band communication signal with center frequency at 2.4 GHz is received by the repeaters. The signal passes through a narrowband bandpass filter to reject unwanted signals and then is up converted to slight different frequencies at 2.6 GHz, 2.8 GHz, 3GHz, …, using mixers with different LO frequencies. The signal is then bandpass filtered, amplified using high gain amplifier (HGA), and transmitted by the TX antenna. Capacitors around 140 PF is used as a DC blocker.

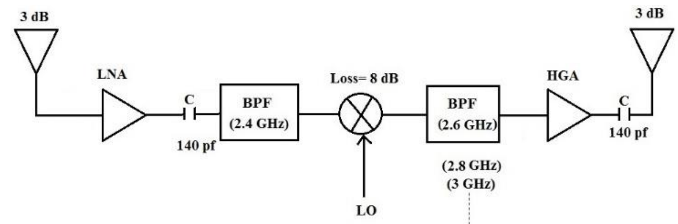

Fig. 4. Repeater block diagram.

V. Conclusion

We have presented our design of a novel wireless adaptive swarm array beamforming system. In the purposed architecture, SA elements act as repeaters, and the element signals are wirelessly beamformed to achieve better power and signal to noise ratio (SNR) at final receiver. The approach doesn't require the knowledge of the direction of arrival (DOA) of the target or SA, doesn't need to obtain the SA element positions and precise SA system synchronization, doesn't need real time calibration, and it is a simple, robust, and efficient way to recover the desired signal sent by the target. Since the proposed adaptive wireless beamforming is performed at the destination rather than the repeaters, the great reduction of hardware and computation burden on the swarm drones is expected.

References

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