Beam Focusing by Scattering from an Array of Scatterers on a Drone

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***Abstract*—Beamforming by scattering from an array of scatterers carried by a drone is explored. By positioning the vertical heights of the scatterers on the drone, beam focusing can be achieved in a desired direction. Various horizontal layouts of the scatterers on the drone can be used, with a "double-cross" layout used here for the case of 9 scatterers. The formation of a null in the pattern in a desired direction is also possible using optimization of the scatterer positions.**

I. Introduction

In some scenarios it may be desirable to relay a signal from a ground-based transceiver to a distant transceiver, such as when there is blockage and thus no direct line-of-sight between the ground-based transceiver and the distant transceiver. The distant transceiver may be also located on the ground or possibly on an airborne platform.

The concept proposed here is based on using a drone as a relay. A single antenna located on the drone will produce a fairly broad radiation pattern in the relayed signal, which may be less than optimal. Here an array of scatterers on the drone is used to radiate a focused beam that points towards the distant transceiver. The concept is illustrated in Fig. 1.

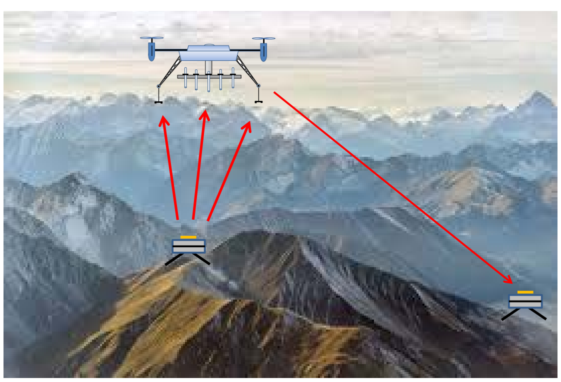

Fig. 1. A drone carrying an array of scatterers, used as a relay when there is no direct line-of-sight between two transceivers.

The vertical position of each scatterer on the drone is used to control the phase of the signal scattered by that particular element. The array of scatterers thus acts as a phased array, with the radiated beam properties dependent on the vertical positions of the scatterers for a given horizontal layout. Amplifiers can be placed at each element to boost up the signal, to increase the radiated signal beyond what can be obtained from the natural scattering from the scatterers. Figure 2 shows a view of an array of scatterers on a drone, assuming the scatterers are vertical resonant dipole elements. If the vertical postings of the scattering elements are adjustable, then the beam properties of the scattered pattern can be adjusted. One objective is to focus the scattered pattern to a desired direction, to point toward the distant transceiver. Another objective could be to introduce one or more nulls into the pattern, in order to reduce interference from a source located in a known direction. The theory for achieving this is discussed in the next section.

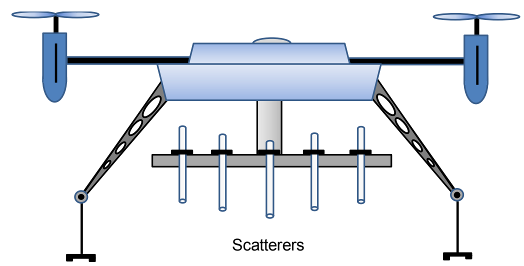

Fig. 2. An illustration of an array of scatterers (shown as vertical dipole elements) suspended below a drone.

II. Beam Focusing Condition

A beam-focusing condition was derived in [1] for a swarm of drones, each carrying a single scatterer. The swarm concept is applicable at low frequency (e.g., lower than 300 MHz), where the drone swarm can be spread out over a significant distance to create an effective phased array that is multiple wavelengths in size. The present concept of having an array of scatterers on a single drone is appropriate at higher frequencies (e.g., above 3 GHz), where the array size is comparable to that of the drone. However, the beam-focusing condition is the same in both cases. Assuming identical scatters, and neglecting mutual impedance, the normalized array factor for the far-field scattered pattern magnitude $F(\theta,\phi)$ for an array of N scatterers is given by [2]

$$F(\theta,\phi)=\left|\sum_{n=1}^{N} e^{-jk_0 r_n} e^{jk_0 x_n \sin\theta\cos\phi} e^{jk_0 y_n \sin\theta\sin\phi} e^{jk_0 z_n \cos\theta}\right|, \quad (1)$$

where r_n is the distance from the ground-based transceiver to the nth scattering element, and the angles (θ, ϕ) are the usual far-field angles in spherical coordinates. This pattern gets multiplied by the element pattern for the scatterers (here simple resonant vertical dipoles). Assuming that the drone is far enough away from the ground-based transceiver so that a far-field approximation may be used for the distance r_n, we have

$$r_n \approx r_s + x_n' \sin\theta_s \cos\phi_s + y_n' \sin\theta_s \sin\phi_s + z_n' \cos\theta_s \,, \quad (2)$$

where r_s is the distance from the ground-based transceiver to a fixed (and somewhat arbitrary) spot on the drone, and the primed coordinates are the locations on the nth scatterer (e.g., the center of the nth scatterer) relative to the location of the fixed drone spot. The angles (θ_s, ϕ_s) are the angles to the drone spot as seen by the ground-based transceiver. The beam-focusing condition comes from enforcing that the scattered field from each element adds in phase in a desired direction (θ_0, ϕ_0) (the direction of the main beam). This results in

$$z_n'\left(\cos\theta_s - \cos\theta_0\right) = x_n'\left(\sin\theta_0 \cos\phi_0 - \sin\theta_s \cos\phi_s\right) + y_n'\left(\sin\theta_0 \sin\phi_0 - \sin\theta_s \sin\phi_s\right). \quad (3)$$

Figure 3 shows the pattern at 3 GHz in the horizontal plane that results from an array of N = 9 scatterers in a "double-cross" formation, for a main beam at (θ_0, ϕ_0) = (90°, 45°).

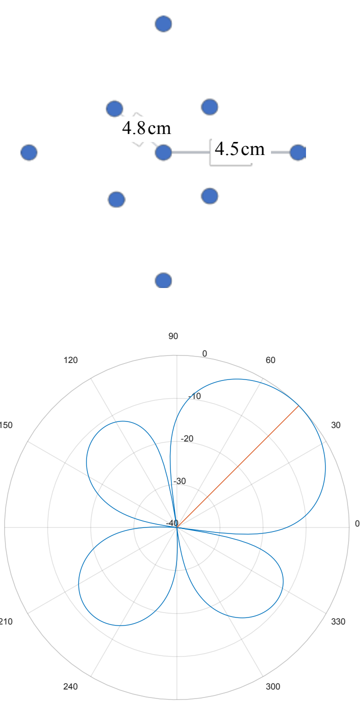

Fig. 3. Above: Horizontal layout of double-cross array. Below: The pattern obtained using the beam-focusing condition.

III. Optimization

For a given horizontal layout of the scatterers, the beam focusing condition determines the vertical elements positions. However, if we allow the vertical positions to be degrees of freedom, the pattern can be optimized in various ways, such as maximizing the directivity, minimizing the sidelobe level, and/or creating a null in the pattern at some specified set of angles (θ_{nill}, ϕ_{null}). Figure 4 shows the pattern in the horizontal plane that results from an optimization, when the objective was to focus the beam at (θ_0, ϕ_0) = (90°, 45°), while also minimizing the sidelobe level, maximizing the directivity, and creating a null at (θ_{nill}, ϕ_{null}) = (45°, 315°). The null is very deep in this specified direction, about -176 dB, and Fig. 4 shows that the null remains lower than -20 dB in the horizontal plane in the direction (90°, 315°).

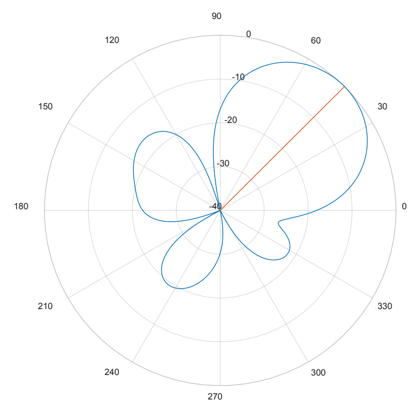

Fig. 4. The pattern obtained after optimization, using the same layout as in Fig. 3.

The patterns shown above are calculated assuming that the scattering elements are scattering a signal that is transmitted from a ground-based transmitter, and thus the drone is acting as a transmitting array. However, reciprocity [3] tells us that the pattern shape when the drone is relaying a signal from the distant transceiver to the ground-based transceiver will be the same.

The above calculations of the array scattering have neglected mutual impedance between the elements. By accounting for mutual impedance effects, it is seen that the main beam is affected marginally, while the null depth is more seriously affected. Optimization in the presence of the mutual impedance can be used to improve the null depth and the overall pattern shape (details are omitted here).

References

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