MITIGATING INTERFERENCE FROM URBAN AIR MOBILITY VEHICLES ON SATELLITE COMMUNICATION LINKS BY USING VORTEX RADIOMETRY

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Abstract

Vortex radiometers (VRs) establish an early warning system for communication channels by generating concentric annular beam patterns around the active link. Peaks in received power are monitored as interfering signals traverse overhead, allowing the VR to estimate source velocity. From this information the VR determines 1) when a fade will occur, 2) how long the fade will persist for and 3) how intense the fade will be. This paper demonstrates how VRs can increase the resilience of communication systems used in urban air mobility applications.

1. Introduction

Air transportation is on the verge of a massive disruption, which will forever change the way people, goods and information travel. Within the next decade package delivery, air metros, taxis and ambulance services will emerge [1]. These markets are collectively described as urban air mobility (UAM) applications. By 2050, the UAM air taxi market will transport around one-hundred thousand people per year, across the globe (Fig. 1) [2]. To service these markets a mix of autonomous and semi-autonomous unmanned aerial vehicles (UAVs) and remotely piloted aircraft (RPAs) are being developed [3].

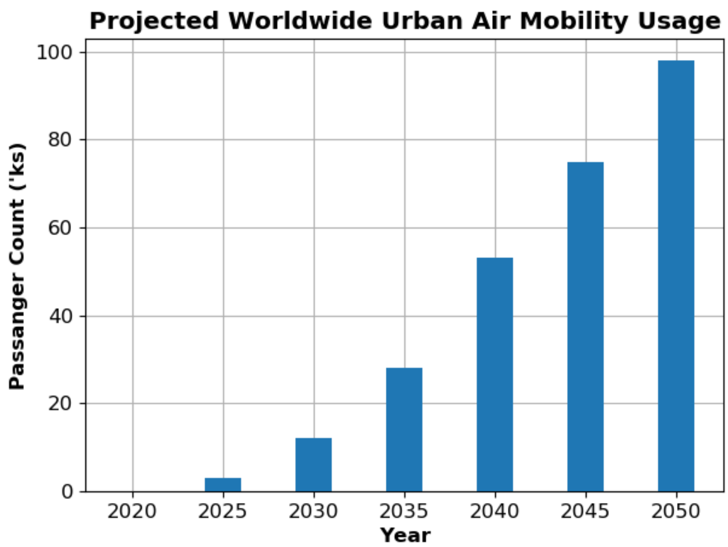


Figure 1: Urban air mobility markets are expected to become extremely popular within the next two decades [2].

While it may not be obvious at first glance, the emergence of UAM will also be disruptive to the radio frequency (RF) communication industry. It's clear that new UAM vehicles will require novel communication technologies for air traffic management, navigation and remote vehicle control. Safety and system resilience are critical factors, especially as flights are expected to be conducted within highly populated cities such as Los Angles, New York and London etc. Air taxi flights within the US alone, are expected to require a minimum of four thousand aircraft [4], each necessitating high data rate communication capabilities.

As the number of UAM vehicles increases, so too does the probability that vital communication links will encounter unexpected interference (Fig. 2). In the worst case scenario, such interference could result in loss of vehicle control leading to catastrophic loss of life, property and public trust in UAM applications. It is therefore absolutely critical to develop technologies capable of mitigating signal interference.

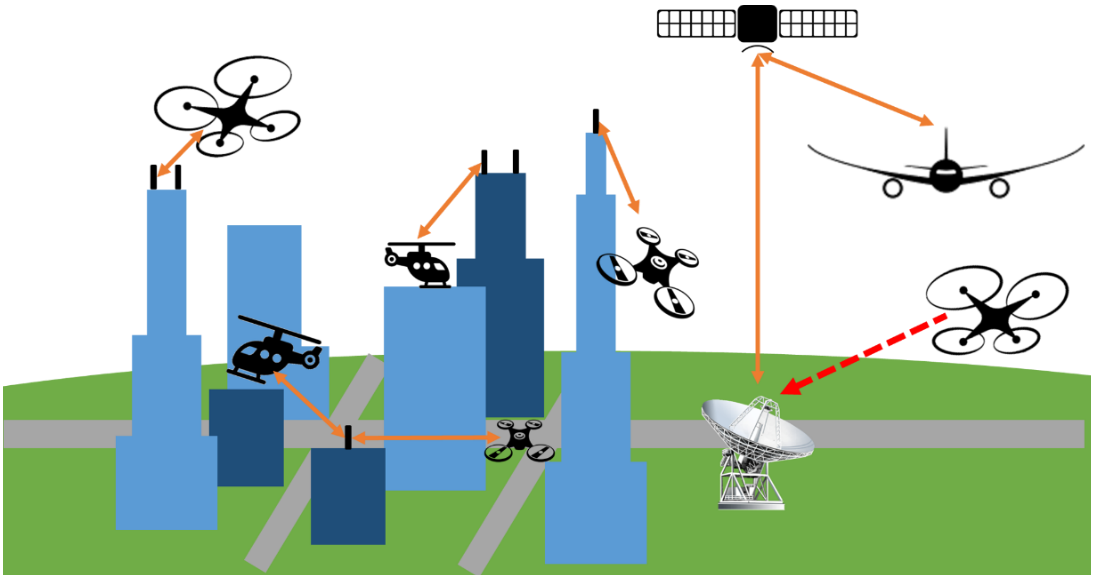


Figure 2: The probability of experiencing signal interference (red line) on a communication link increases as the number of in-service UAM vehicles increase. Therefore, technologies must be developed in order to increase resiliency of the RF communication infrastructure.

Future RF networks will possess cognitive abilities [5], enabling terrestrial 5G and satellite communication (SATCOM) systems, including low-earth-orbit (LEO) constellations and high bandwidth geostationary orbit (GEO) platforms, to be integrated seamlessly. The cognitive aspect of these networks enables links between assets to be adjusted autonomously, based on instantaneous network performance statistics. As such, cognitive networks will become vital enabling infrastructure for UAM applications.

A significant amount of current research is focused on developing cognitive algorithms to detect signal interference and then alter the link by changing frequency, switching to a different transceiver or adjusting amplification levels etc. The trouble with this approach is that it relies on measuring the performance of the communication link itself, and therefore the link is still susceptible to interference induced fades for short amounts of time. Yet, in the UAM world, losing a communication link for even a short amount of time can have disastrous implications. A new approach, capable of detecting signal interference before it impacts the communication link, is therefore required.

2. Fundamental aspects of Vortex Radiometry

Vortex radiometry (VR) is an ideal technology to detect signal interference before the communication link is negatively impacted. VRs exploit the orbital angular momentum (OAM) properties of electromagnetic fields [6], in order to generate concentric annular beam patterns around a communication link [7]. The concentric annular beams act as an early warning system for the communicating antenna (Fig 3).

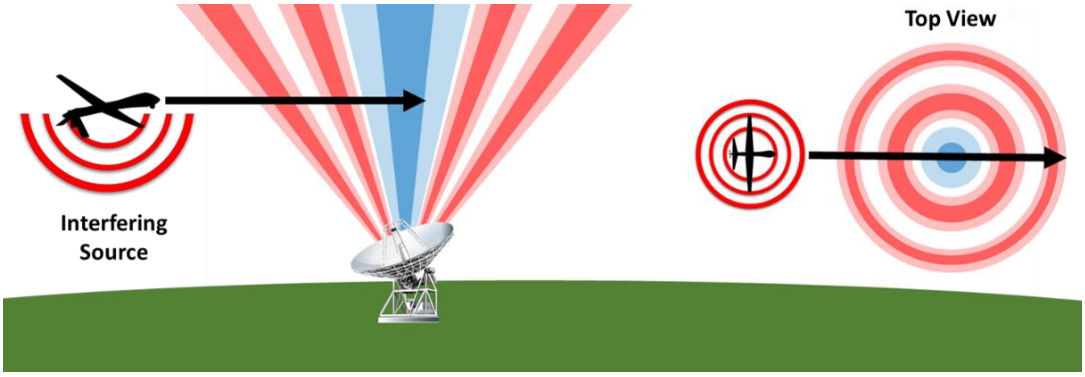


Figure 3: Concentric annular beams, generated by a VR, enable a communicating antenna to detect and characterize incoming sources of interference before they negatively impact the communication link. In this case, a UAV broadcasting on the wrong frequency is identified by a two-beam VR system.

Concentric annular antenna patterns are generated by injecting OAM into the received, interfering electric field. The simplest method to accomplish this is to place a spiral phase plate (SPP) into the beam path (Fig. 4) [8]. SPPs change the electric field's azimuthal mode number according to,

$$\Delta l = \frac{h \cdot \Delta n}{\lambda}, \tag{1}$$

where Δl is the change is azimuthal mode number, h is the step heigth of the SPP (i.e. maximum thickness change), Δn is the difference between the refractive index of the SPP material and air and finally, λ is the incident radiation's wavelength. The resulting annular beam pattern has a radius of,

$$r = \omega\sqrt{\frac{|l|}{2}}. \tag{2}$$

Here, ω is the Gaussian beam radius for a beam with no OAM (i.e. $l = 0$).

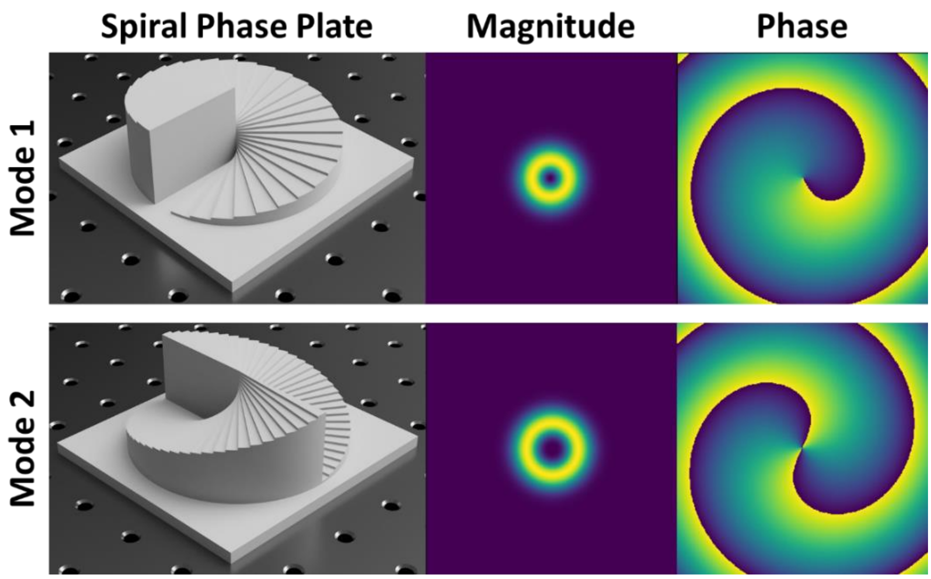


Figure 4: VR beams are generated by inducing OAM into the received electric field. The spiral phase plate (SPP) is perhaps this simplest method to generate OAM (left column). Place an SPP in front of an antenna results in an annular magnitude field (middle column) and a helical phase front (right column).

In a multi-beam VR system, a traversing interference source intersects the outermost beam first, producing a peak in received power. This is followed by a peak in received power on subsequent beam. If the altitude of the interfering source is known (by utilizing existing on-board traffic avoidance systems), it is then possible to estimate the source velocity using the time between the received power peaks and their known separation distance. The time-of-impact (TOI), or time at which the interfering source will be directly over the communication link is determined using the simple distance over time velocity relation. Finally, the strength of the interference is estimated by monitoring received power levels on each of the VR beams. Full details of these calculations are presented in [9].

Vortex radiometers enable communication systems to determine 1) when an interference induced fade will occur, 2) how long the fade will persist for and 3) how intense the fade will be. Integrating VRs into cognitive radios results in an extremely resilient system capable of mitigating interference before it occurs. The following section demonstrates how VRs are used to mitigate interference between UAM vehicles utilizing SATCOM and terrestrial links.

3. Simulation

Consider a scenario in which a UAM air metro vehicle has just picked up passengers at a designated landing pad. The vehicle is controlled by a remote pilot using the primary communication link with a GEO satellite (26 GHz). A secondary link (4 GHz) with a terrestrial cellular-like base station provides redundancy. Just before take-off, an autonomous package delivery vehicle (PDV) passes nearby and mistakenly identifies the air metro vehicle as a base station (Fig. 5). The PDV interprets the lack of response from the air metro as poor link performance, and therefore autonomously increases its transmitting power to excessively high levels in order to establish a positive link margin. This high level of interference could cause the air metro to crash if it were to continue its take-off procedure as intended.

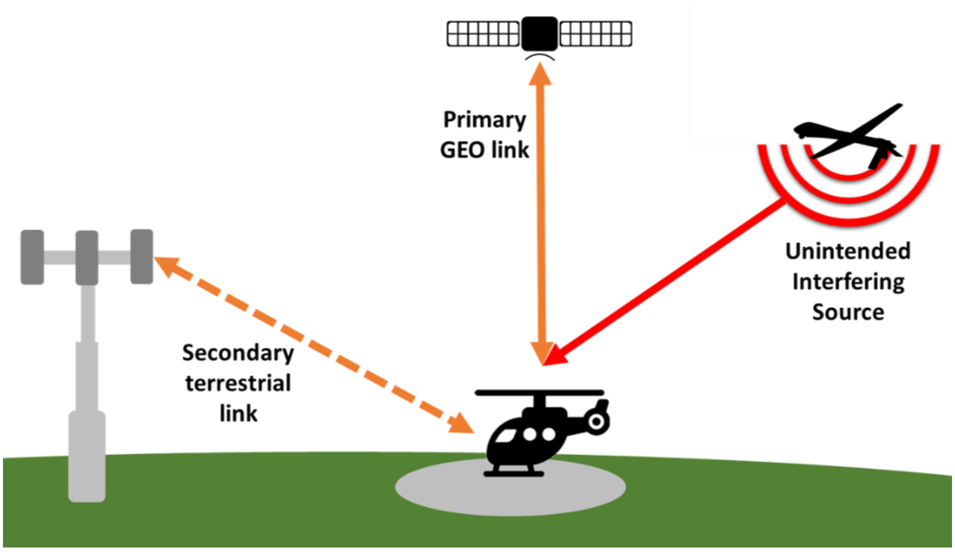


Figure 5: An urban air taxi is about to take-off, when an interfering source approaches. Without VR capabilities, the air metro's primary link is disrupted, potentially causing loss of control. However, when VR capabilities are enabled, the air metro identifies to interference and switches to the secondary communication link.

Equipping the air metro vehicle with a multi-beam VR system enables the on-board communication system to identify the interfering source and transition from the primary GEO link to a secondary terrestrial link, before communications are interrupted. Table 1 shows the parameters of each available communication link.

Table 1

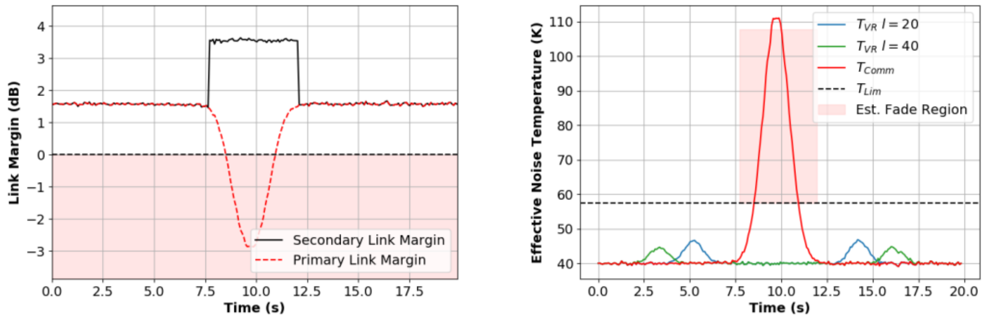
Parameter	Units	Primary GEO Link	Secondary Link
Frequency	GHz	26	4
Transmitter Power	W	1	0.001
Transmitter Diameter	m	2	0.05
Effective Efficiency	-	0.6	0.01
MODCOD	-	BPSK - Uncoded	BPSK - Uncoded
Data Rate	Mbps	100	100
Bit Error Rate	-	1e-6	1e-6
Range	km	35786	0.2
Receiver Diameter	m	0.4	0.05
Receiver Efficiency	-	0.6	0.1

The VR system utilizes two beams with azimuthal mode numbers of 20 and 40 respectively. Table 2 outlines the characteristics of the interfering PDV source.

Table 2

Parameter	Units	Interfering Source
Frequency	GHz	26
Effective Noise Temperature	K	2000
Effective Radius	m	5
Velocity	kts	50
Altitude	m	2000

Without VR capabilities enabled, the primary GEO communication link fades as the PDV passes over the air metro vehicle. This is evident by observing the red link margin trace in Fig. 6a. This situation can be avoided by having the VR instruct the air metro's radio to switch from the primary to secondary link, resulting in a positive active link margin (black line). The VR does this by informing the communication system of 1) when the fade will occur, 2) how long it will persist for and 3) how intense the fade will be, by observing received power levels on each VR beam and applying the control algorithm outlined in [9] (Fig. 6b).



(a) (b)

Figure 6: Enabling VR capabilities allows the air metro vehicle to transition from the primary GEO link to the secondary terrestrial link, thereby ensuring that the active link margin stays positive (a). The VR instructs the on-board cognitive radio to switch to the secondary link by monitoring received power levels on each individual VR beam (b).

4. Conclusions

Urban air mobility is poised to change the way people and goods move throughout and between the world's largest cities. However, the anticipated increase in in-service aircraft will put significant strains on existing communication systems. Autonomous, cognitive networks will be required to handle the impending work load, and unintended consequences are a certainty. Therefore, technologies must be developed in order to provide resiliency to UAM communication systems.

Vortex radiometers have the ability to fill this technology gap, by providing cognitive communication systems with measured knowledge of 1) when a fade will occur, 2) how long the fade will persist for and 3) how intense the fade will be. This is accomplished by exploiting the orbital angular momentum properties of electromagnetic fields, in order to establish concentric annular beam patterns around a communication channel. Traversing interfering sources are identified in each beam, allowing the source velocity and intensity to be estimated and the fade TOI and intensity to be determined.

5. References

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