Intruder Drone Detection using Unmanned Aerial Vehicle Borne Radar (UAVBR) via Reconfigurable Intelligent Reflective Surface (IRS)

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***Abstract*—Easy availability of the Drones/Unmanned Aerial Vehicles (UAVs) may lead to a carping situation. This makes it important to detect the presence of the Intruder drone in any particular area. Towards this matter, work is taken up on detection of intruder drone using UAV Borne Radar (UAVBR) via Reconfigurable Intelligent Reflective Surface (IRS). Direct Line of Sight (LoS) scenario may occur while detection of intruder drone but signal may be weak. So, to increase the probability of detection of intruder drone Reconfigurable IRS is used with various pattern of IRS such as Uniform Linear Array (ULA), Uniform Rectangular Array (URA) and Uniform Circular Array (UCA). Further, performance analysis is done by considering different parameters in Matlab software.**

***Index Terms*—Intruder Drone , UAVBR, Reconfigurable IRS, Detection.**

I. Introduction

Enormous growth of the Drone/UAV technology has crossed all the hard conventional barrier of both military and non-military sectors. Operation of drone is beneficial from monitoring a remote inaccessible area to the agriculture field applications [1]. New technology brings revolutionary change around the world along with new challenges. Anti-social activities such as dropping of explosives, spying an area, smuggling, etc., using drones led to a carping situation [2].

This situation makes it important to detect the Intruder Drone in the prohibited area. There are several work done by the researchers towards the detection of the UAV. For the detection of drone camera is used in [3], but it is not suitable for Non-Light of Sight (NLoS) condition. In [4], author used tetrahedral acoustic microphone array to detect the presence of drone but the estimation of the azimuth and elevetion angle is provided with low accuracy. Morris *et al.* [5] used radar for detection even in harsh condition such as rain, fog, etc.

In practical scenario, sometimes intruder drone may be hidden, not present in the range of the sensor to detect or the (LoS) signal may be weak. So, for the multipath or NLoS scenario IRS can be used which increases the coverage area [6] and the capability for the detection of the intruder drone. IRS is a meta-electromagnetic surface with large number of passive elements which pertains the property of reflection, refraction, and absorption can be controlled electrically or software defined way by the control station [7].

There are few work done towards improving the energy and spectral efficiency in NLoS scenario using IRS [6], coverage analysis of the IRS aided communication system, channel modelling for the UAV aided IRS OFDMA system [8], enhancing the cellular communication of the UAV by analysing the parameters such as optimal distance between the IRS and Base-station, signal gain as a function of height of the UAV [7], etc. But it could be observed that IRS is not being used for the intruder drone detection application yet. So, here in this paper, work is taken up on detecting the intruder drone using UAVBR via reconfigurable IRS.

The important advantages of the proposed method in detection of intruder drone are summarized as follows:

- Using IRS, the probability of intruder drone detection in the particular area of surveillance will increase.
- Reconfigurable IRS with various pattern of passive elements such as ULA, URA and UCA are analysed for optimal performance of the detection system without much constraining about the altitude, speed and distance of patrolling UAV in all day-night condition.

The rest of the paper is arranged as follows. Section II contains the description of the system model along with signal model and the brief explaination about the detection of intruder drone. Section III, contains the simulation results of the proposed technique. Finally, section IV concludes the work.

II. Proposed System and Signal Model for the Detection of Intruder Drone

A. Proposed System Model

Proposed system model is depicted in Fig. 1 for the detection of intruder drone in the restricted area. UAVBR is used to detect the intruder drone. Radar transmits signal in the surveillance area to interrogate the presence of any intruder drone. Reflected signal from the intruder drone signify its presence in the surrounding. But due to the presence

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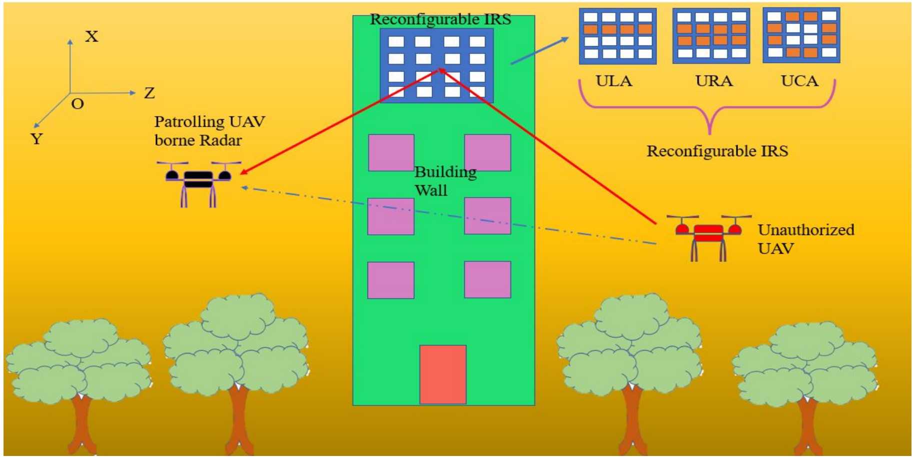

Fig. 1: Proposed System Model

of obstacles or weak signal there is a possibility of miss detection. In order to avoid that situation IRS is placed on the wall of the building. IRS consists of $M = M_x \times M_z$ elements, which can be reconfigured or controlled to enhance the performance of the system. After the availability of the intruder drone information in the IRS, the reflected signal is combined from all the active elements of the IRS towards the patrolling UAVBR. After the reception of the data, Patrolling UAVBR could transmit the data to the nearest ground station.

Let the total task operating system for surveillance be T. At the time instant t the location of the patrolling UAVBR is given by $l_{UAVBR}(t) = [x_p(t), y_p(t), h_p(t)]^T$. Reconfigurable IRS is deployed on a wall parallel to the XOZ plane. Let the separation between the IRS elements are considered as δ_x and δ_z respectively. The location of the first element of the IRS can be denoted as $l_{IRS0} = [x_{R0}, 0, z_{R0}]^T$. So, the location of the $(m_x, m_z)^{th}$ element can be denoted as $l_{IRSm} = [x_{R0} + (m_x - 1)\delta_x, 0, z_{R0} + (m_z - 1)\delta_z]^T$.

B. Proposed Signal Model

The signal modelling of the proposed system model can be described as follows.

The received signal at the patrolling UAVBR is represented as [8],

$$y(t) = H_{UI}(t)s(t) + \sum_{m=0}^{M} H_{RU}^H(t)\Phi(t)H_{IR}(t)s(t) + u(t) \quad (1)$$

where, $H_{UI}(t)$ is the channel matrix between the intruder drone and UAVBR in LoS condition, $H_{RU}(t)$ is the channel matrix between the IRS and patrolling UAVBR, $H_{IR}(t)$ is the channel matrix between the intruder drone and IRS, $\Phi(t) = diag(e^{j\phi_1}, e^{j\phi_2}, ..., e^{j\phi_M})$ with $\phi_m \in [0, 2\pi]$ is the phase shift variable for the IRS element, $s(t)$ is the signal intruder drone signal received by the radar, $u(t)$ is the gaussian noise. For simplicity, (1) can be represented as,

$$y(t) = b(t) + u(t) \quad (2)$$

The channel matrix $H_{IR}(t)$ can be represented as [8],

$$H_{IR}(t) = \sum_{l=0}^{M-1} h_{IR} a_r(\psi_{r,m}(t), \theta_{r,m}(t)) e^{j\frac{2\pi}{\lambda}\int_{t_0}^{t} f_d(t)dt} \quad (3)$$

where, h_{IR} represents the channel coefficient, $a_r(\psi_{r,l}(t), \theta_{r,l}(t))$ is the steering vector of reconfigurable IRS which changes as the pattern of the active elements changes, $f_d(t)$ is the Doppler frequency of the intruder drone with which it is moving.

For reconfigurable IRS various pattern such as ULA, URA and UCA are considered here for this work. The array response of the reconfigurable IRS could be represented as,
For URA [8]:

$$a_r(\psi_{r,l}(t), \theta_{r,l}(t)) = [1, ..., e^{j\frac{2\pi}{\lambda}\delta(\beta sin\psi(t) sin\theta(t) + \gamma cos\theta(t))}, ..., e^{j\frac{2\pi}{\lambda}((M_x-1)\delta sin\psi(t) sin\theta(t) + (M_z-1)cos\theta(t))}]^T \quad (4)$$

For ULA [8]:

$$a_r(\psi_{r,l}(t)) = [1, ..., e^{j\frac{2\pi}{\lambda}\delta sin\psi(t)}, ..., e^{j\frac{2\pi}{\lambda}(M-1)\delta sin\psi(t)}]^T \quad (5)$$

For UCA [9]:

$$a_r(\psi_{r,l}(t), \theta_{r,l}(t)) = [e^{j\frac{2\pi}{\lambda}d(cos\psi_1(t) cos\theta(t) + sin\psi_1(t) sin\theta(t))}, ..., e^{j\frac{2\pi}{\lambda}d((M_x-1)cos\psi(t) cos\theta(t) + (M_z-1)sin\psi(t) sin\theta(t))}]^T \quad (6)$$

where, d is the radius of the UCA pattern.

C. Detection of Intruder Drone using Generalized Likelihood Ratio Test (GLRT) detector

For the detection of the Intruder Drone, two cases can be considered. Let the null hypothesis (H_0) be such that the received data is free from intruder drone echoes and the alternative hypothesis (H_1) be such that the received data contains the target echoes. The detection problem can be represented as [10],

$$H_0 : y(t) = u(t), \qquad \forall\ t = 1, ..., T$$
$$H_1 : y(t) = b(t) + u(t), \qquad \forall\ t = 1, ..., T \tag{7}$$

For detecting intruder GLRT detector is considered for this scenario, which can be represented as [10],

$$\frac{max_{b,\sigma^2} f(Y/H_1)}{max_b f(Y/H_0)} \underset{H_0}{\overset{H_1}{\gtrless}} \eta \tag{8}$$

where, η is the detection threshold, $f(Y/H_1)$, $f(Y/H_0)$ are the probability density function (PDF) of the received signal under H_0, H_1 respectively.

$$f(Y/H_1) = \frac{1}{\pi^M \sigma^{2M}} exp - (\frac{1}{\sigma^2} \sum_{l=1}^{M} ||y(t) - b(t)||^2) \tag{9}$$

$$f(Y/H_0) = \frac{1}{\pi^M \sigma^{2M}} exp - (\frac{1}{\sigma^2} \sum_{l=1}^{M} ||y(t)||^2) \tag{10}$$

The further steps for Probability of False alarm, P_{FA} and Probability of detection P_D is followed in the similar line as in [10]. The simulation results are presented in the next section.

III. Simulation Results

In this section, performance evaluation of the proposed system is analysed by considering different parameters. The parameters for the simulation are represented in Table 1.

Table. 1. Parameters used for simulation [8]

Parameters	Values
Carrier frequency	2GHz
Reflection power loss of IRS	1 dB
Height of UAVBR	25m
Height of Reconfigurable IRS center	50m
Height of Intruder drone	10m
Number of Reconfigurable IRS element	64
Distance between UAVBR and Reconfigurable IRS	35m

A. Performance analysis based on Probability of detection (P_D) and Probability of false alarm (P_{FA})

In Fig. 2 P_D vs P_{FA} is plotted by considering SNR=10 dB. It could be observed that for UCA configuration the probability of detection of intruder drone is more as compared to ULA and URA. Similarly, in Fig. 3 P_D is plotted by varying SNR for different IRS configuration. It can be observed that probability of detection uaing IRS is more as compared to Non-IRS (LoS) situation. Both Fig. 2 and 3 depicts that for UCA configuration intruder drone detection is more.

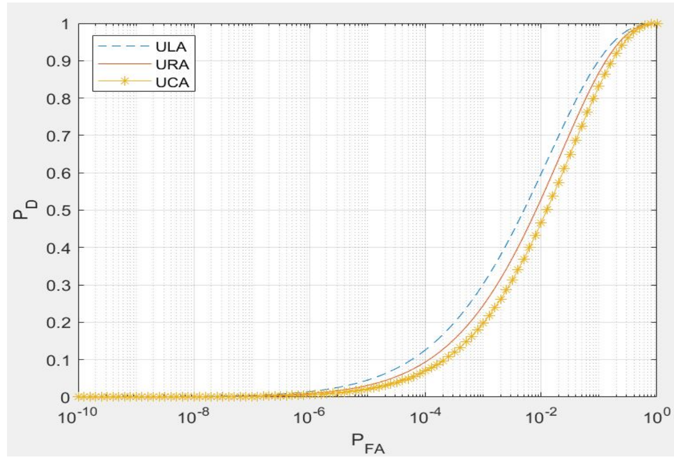

Fig. 2: Receiver Operating Characteristics (ROC)

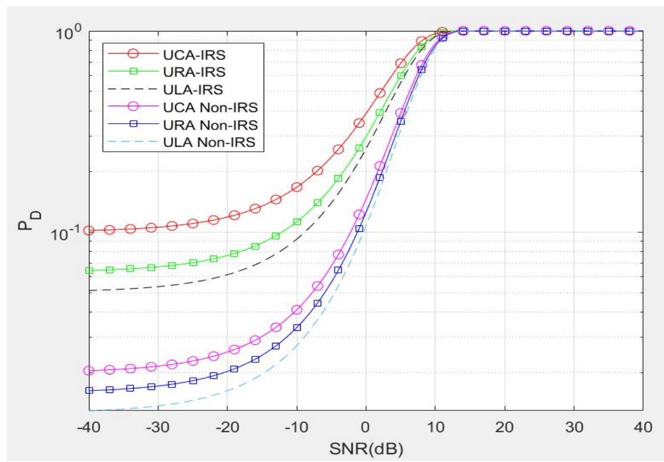

Fig. 3: Probability of Detection by varying SNR

B. Received Signal gain with respect to the number of active Reconfigurable IRS elements

The signal received from the intruder drone is analysed by considering the IRS gain [8] by varying the number of IRS element. Along with the number of elements of IRS, configuration is varied to analyze its gain for different height of UAVBR. In Fig. 4 it could be depicted that as the number of active IRS elements increases gain also increases. For every height of UAVBR, different configurations are analysed such as ULA, URA and UCA. From Fig. 4 it could be observed that the UCA outperforms for all the height and IRS elements. By increasing the number of active IRS elements, more energy can be received from the intruder drone as more EM waves can be reflected to the UAVBR. Hence, the gain of the IRS increases.

C. Reconfigurable IRS gain with respect to the height of the UAVBR

Fig. 5 depicts the signal gain at the IRS for particular distance between the Reconfigurable IRS and UAVBR. It could be observed that for all the three distance i.e., 30, 50

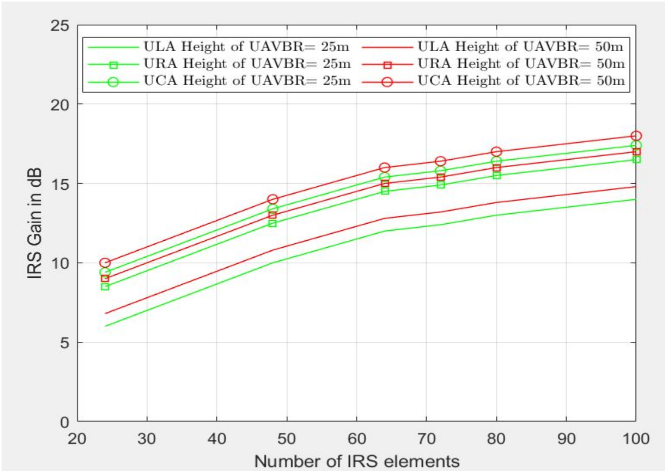

Fig. 4: IRS gain vs Number of IRS elements

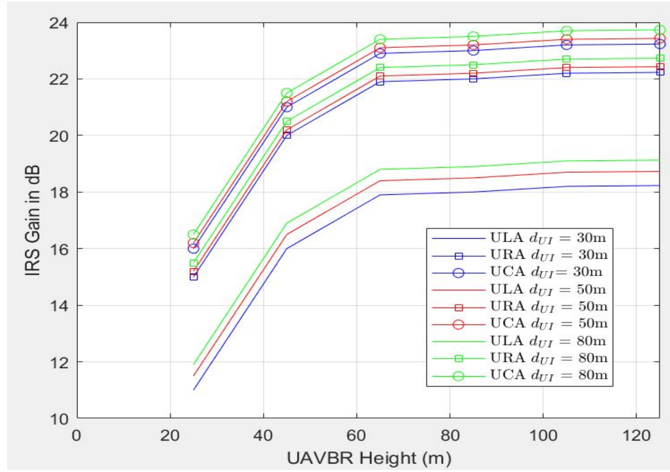

Fig. 5: IRS gain vs UAVBR height

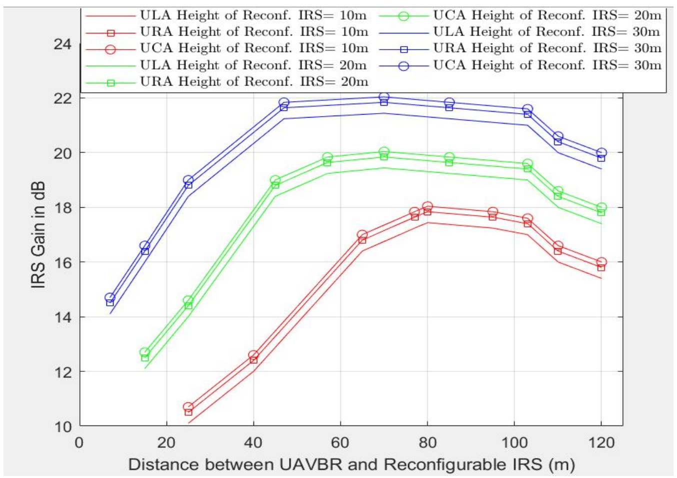

Fig. 6: IRS gain vs Distance between the UAVBR and Reconfigurable IRS varying Height of Reconfigurable IRS

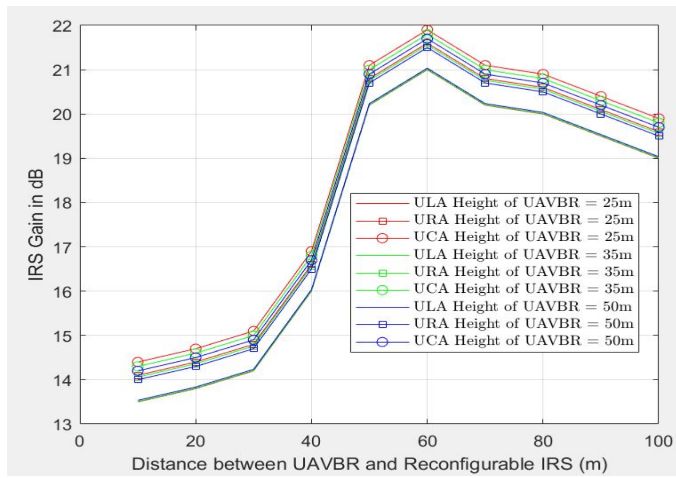

Fig. 7: IRS gain vs Distance between the UAVBR and Reconfigurable IRS varying Height of UAVBR

and 80m considered, the gain increases upto 60m height and then it saturates. Though the saturation point of all the three configuration are same but the signal power in UCA and URA increases more rapidly than ULA.

D. Reconfigurable IRS gain with respect to the location of the UAVBR

Fig. 6 depicts the signal gain achieved by the IRS by varying the distance between the UAVBR and Reconfigurable IRS. At all the three heights considered such as 10, 20 and 30m as the distance increases initially the gain increases after a optimal distance around 80m the gain decreases. In all the three configuration in case of UCA signal gain achieved is more as compared to ULA and URA.

E. Reconfigurable IRS gain with respect to the location of the IRS

For different height of Reconfigurable IRS deployed on the building wall signal gain is plotted which is depicted in Fig. 7. Though the Reconfigurable IRS placement on the height variation does not show much change in the gain but by changing the configuration of the IRS significant increase in the gain is observed.

IV. Conclusion

In this paper, detection of the intruder drone using UAVBR is done using reconfigurable IRS. Though the direct signal i.e., LoS signal is present but it may be weak which may result into miss detection of intruder drone. So, Reconfigurable IRS could be used which increases the chances of the detection. By analysis with different parameters it could be observed that UCA configuration of the IRS outperforms in all the considered situation.

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