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Research Into the Possibility of Creating a Wi-Fi Radar for Detecting Moving Flying Targets in the Nearby Area of Protected Objects

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***Abstract*— Nowadays, there are much researches on the creation of passive coherent radar systems for detecting aircraft in the airspace. One of them is the use of systems based on Wi Fi signals for detecting a moving target. This paper research the possibility of detecting and determining the parameters of flying targets using Wi Fi radar in nearby area of protected objects. An analysis of the potential capabilities of such a system has been carried out. The conclusion is that the development of such a system is possible for close distances to the protected object.**

Keywords*— *bistatic passive radar, Wi Fi.

I. INTRODUCTION

Nowadays we are witnessing a great spread of unmanned aerial vehicles. Many people have them for entertainment purposes because they are easily accessible in price, and they can see things from a bird's eye view. There are enthusiasts who make their own unmanned aerial vehicles. There are also those who violate legal restrictions. There is a problem of protecting critical infrastructure objects that are protected from the entry of unmanned aerial vehicles, although legal software does not allow this, there are ways to hack the software. Proof of this is the entry of an unmanned aerial vehicle at Sofia Airport on February 7, 2025 [1] as a result, there are delays to 6 flights and the possibility of a much more serious incident.

In such a case, there is a need for timely detection of aircraft and establishing the moment of entry into the boundaries of the given object. One way to establish this is through radars that can detect the target and determine its parameters. To protect objects from such an entry, reconnaissance at long distances is not necessary, as is the case with most radar systems, but a short distance beyond the borders of the object with sufficient resolution in distance and angular coordinates is enough. There are many literary sources [3], [4], [7], [8], [9], [10] that study the methods for creating passive radars. Most Wi-Fi-based systems are used to detect people due to the low power of the transmitter and the small detection distance. The idea of the study is to examine whether it is possible to achieve this using a Wi-Fi semi-passive or pseudo-passive bistatic coherent radar for detecting drones at close distances to a protected object (although the research conducted is applicable to any bistatic radar with similar parameters). The research is related to small amateur aircraft, and their classification is discussed in [2].

The paper is organized as follows. First, a review of radar systems with advantages and disadvantages is made. Then, potential abilities for detecting targets in a bistatic Wi-Fi radar are considered. After that, result and discussion. At the end there is conclusions and acknowledgments.

II. MATERIALS AND METHODS

There are two options for building a radar system to monitor the area near an object and the moment of the target entering the territory of the protected object:

A. The first option is to build an active radar. Its advantages are the ability to determine the signal parameters, such as power, frequency retuning, signal formation, etc. Disadvantages: such a system may be quite expensive to purchase.

B. The second option of a radar system and probably cheaper is to build it as a passive radar, which uses a foreign transmitter to detect and determine the coordinates of the target. Several options for such radars are possible, such as those of the radio broadcasting system, TV broadcasting, Satellite communications, GSM communication, Wi Fi communications. The geometry of a bistatic passive radar system has the form shown in "Fig. 1"

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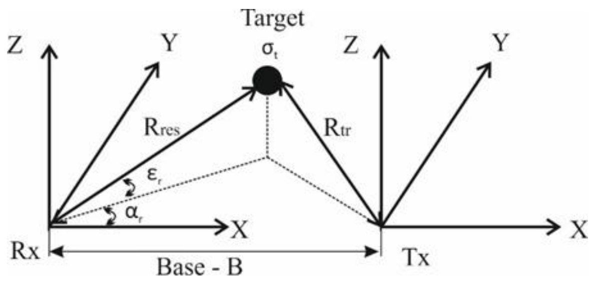

Fig. 1. Geometry of bistatic passive radar.

These systems extract information about the object from the delay time of the signal from the target relative to the direct channel of the transmitted signal. The receiver used in most literature sources [7], [8], [9], [10], [11], [12], [13], [14], [15] uses Software Defined Radio, through which signal processing and spectral analysis are performed.

The signal sources for passive radars can be different and their advantages and disadvantages are discussed below:

a) Analog broadcasting - nowadays TV broadcasting in most countries of the world is digital but passive radars can use radio analogue broadcasting if the country has. Advantages is a high power of the transmitted signal through which targets can be detected at a long distance. Analogue broadcasting has one main disadvantage [3] low resolution depending on the signal spectrum in the context of the transmitted information (music, speech, etc.).

b) Digital TV [3], [7] (DVB-T, DVB-T2) can be used to solve the problem. Advantages: much better resolution compared to the analogue transmitter, low level of side-sheets in the correlation function, independence of the signal spectrum from the message. Disadvantages: lower power than that of analogue television, which reduces the detection distance of especially small targets. Influence of the relief on the detection zone at a distance from the protected object.

c) GSM system [3], [10] – if near the protected object there are base stations of mobile operators, their use is possible for detecting flying objects near the area of the protected object. Advantages: good resolution than analogue broadcast, operation on different frequency bands of the transmitter. Disadvantages – low transmitter power, which significantly reduces the surveillance area, no ability to determine the location and parameters of the transmitter, low accessibility.

d) Wi Fi systems [3], [8], [9] – ability to detect objects at short distances. Disadvantages – low transmitter power, which significantly limits the surveillance area, big side lobes on ambiguity function low range resolution. Advantages if a pseudo-passive system is used (own transmitter with a suitable amplifier) possibility of determining the location of the transmitter for the best resolution. Possibility of manipulating the signal emitted by the transmitter for the purpose of better resolution. From the transmitters examined it is seen that for any conditions (relief, distance of the object from the transmitter) for detecting targets in the area near a given object it is possible to use your own Wi Fi transmitter with a suitable amplifier to increase the power.

In this study, the protected object area is understood as the region that is prohibited for flights of unmanned aerial vehicles. In Bulgaria, these zones are updated every 15 minutes and are provided by the Directorate General "Civil Aviation Administration". They contain information about the coordinates of the object area and restrictions. Looking at the interactive map of the no-fly zones for unmanned aerial vehicles [16], it is seen that there are zones of different sizes and shapes. The flight height in the zones is limited to 150 m or below, but in Bulgaria it is forbidden for unmanned aerial vehicles to fly above this height.

For simplicity, under the protected object area in this article an idealized zone in the shape of a rectangular parallelepiped lying on the ground surface is assumed, its base is flat with a length of 2500 meters by a width of 2000 meters and a height of 200 meters. The transmitter and receiver of the bistatic radar are located equidistantly from the center of the rectangular base in a line along its longitudinal axis. To perform the task, it is not necessary to know anything about the flights of unmanned aerial vehicles outside the area. It is important to detect entry into the zone and monitor drone flights inside the area. In this case, a bistatic range of about 3000 meters is assumed to be sufficient for detection, which is sufficient to cover the dimensions of the object.

In the next part, the potential capabilities of this system are examined and analysed.

First of them is the range and minimal power to detect target.

The operating range of a monostatic coherent radar is determined according to [5], [6].

$$R^4 = \frac{P_{tr} G_{tr} \sigma_t G_{res} \lambda^2 \Delta f T_{acc}}{4\pi^3 q_{min} P_n} \qquad (1)$$

Where: R – the maximum detection range of the radar, P_{tr} – the transmitter power, G_{tr} – the directional coefficient of the transmitter antenna, σ_t – the effective reflecting surface of the target, G_{res} – the directional coefficient of the receiver antenna, λ – wavelength, Δf – the receiver passband, T_{acc} – the time for coherent signal accumulation, q_{min} – the required minimum signal-to-noise ratio, P_n – the noise power at the receiver input.

In the bistatic geometry of passive radar Tx and Rx are not in the same position. According to this the distance between Tx and target (R_{tr}) and Rx and target (R_{res}) need to be distributed. In this case, we can assume that $R = \sqrt{R_{tr} R_{res}}$. Then we can assume that $P_{resmin}=q_{min}P_n$ is a minimal power at the receiver input that can be distinguished from the receiver. In this case (1) can be written for bistatic geometry as [4]:

$$(R_{tr}R_{res})^2 = \frac{P_{tr}G_{tr}\sigma_t G_{res}\lambda^2 \Delta f T_{acc}}{4\pi^3 P_{res_{min}}} \quad (2)$$

Solving (2) for P_{resmin} we will get information about what power we will need for the receiver to find the target.

$$P_{res_{min}} = \frac{P_{tr}G_{tr}\sigma_t G_{res}\lambda^2 \Delta f T_{acc}}{4\pi^3 (R_{tr}R_{res})^2} \quad (3)$$

(3) shows the minimum required value of the receiver input power in an idealized space to achieve the maximum value of the radar range, with several factors affecting wave propagation eliminated.

Next of the potential capabilities is range resolution. The potential range resolution Δr of passive radar is calculated according to [3].

$$\Delta r = \frac{c}{2\Delta f_0}\left(\frac{r_\Sigma^2 - 2r_\Sigma cos\alpha_r cos\varepsilon_r + B^2}{(r_\Sigma - Bcos\alpha_r cos\varepsilon_r)^2}\right) = \\ = \Delta R\alpha \quad (4)$$

Where: c- speed of light, Δf_0 – width of the spectrum of the signal from the transmitter, $r_\Sigma = R_{tr} + R_{res}$ – the total distance between Tx, target and Rx, B – the length of base of bistatic radar, α_r – azimuth of the target, ε_r – elevation angle to the target, $\Delta R = \frac{c}{2\Delta f_0}$ – the resolution of a monostatic radar with same parameters of the signal, $\alpha = \frac{r_\Sigma^2 - 2r_\Sigma cos\alpha_r cos\varepsilon_r + B^2}{(r_\Sigma - Bcos\alpha_r cos\varepsilon_r)^2}$ – coefficient by which the resolution of the bistatic radar is reduced.

Analyzing (4) we can see that the resolution of the bistatic radar in the best-case approaches and becomes equal to the range resolution of the monostatic radar. The lowest resolution will be when the target lies on the base of a bistatic radar on the ground surface, in which case Δr tends to ∞.

The last is how much power in the target channel we will have from transmitter.

One of the major problems in a passive radar is to detect the weak signals from the targets against the strong signal coming directly from the transmitter. To estimate the impact of the direct channel on target detection, the equation given in [3] is used. Its calculation is given by the expression:

$$\frac{P_{direct}}{P_t} = 10lg\frac{4\pi(R_{tr}R_{res})^2}{B\sigma_t}\eta, [dB] \quad (5)$$

Where: η – coefficient of energy leaked from the side lobes of the directional antenna. P_{direct} – the power coming directly from the transmitter, P_t – power coming from the target.

III. Results and Discussion

It is necessary to clarify that the results obtained in this study do not apply only to Wi-Fi systems but are applicable to any bistatic radar with similar parameters such as frequency (respectively wavelength), bandwidth, etc.

The result of (3) for P_{resmin} of different values of $\sqrt{R_{tr}R_{res}}$, σt and T_{acc} are given in Fig. 2. Where for the P_{resmin} in [dBm] is used the equation:

$$P_{res_{min}} = 10\lg\left(\frac{P_{res_{min}}}{10^{-3}}\right), [\text{dBm}] \quad (6)$$

The following values were used to obtain the graphs. In Bulgaria, the maximum power for Wi-Fi transmitter is limited to 2 W, therefore it is accepted P_{tr}=2W. The bistatic radar will use one isotropic antenna for transmitter and one directional antenna with a gain of 20 dBm therefore G_{tr}=1, G_{res}=100. The parameters of the signal are λ=0,125 m and Δf=20 MHz.

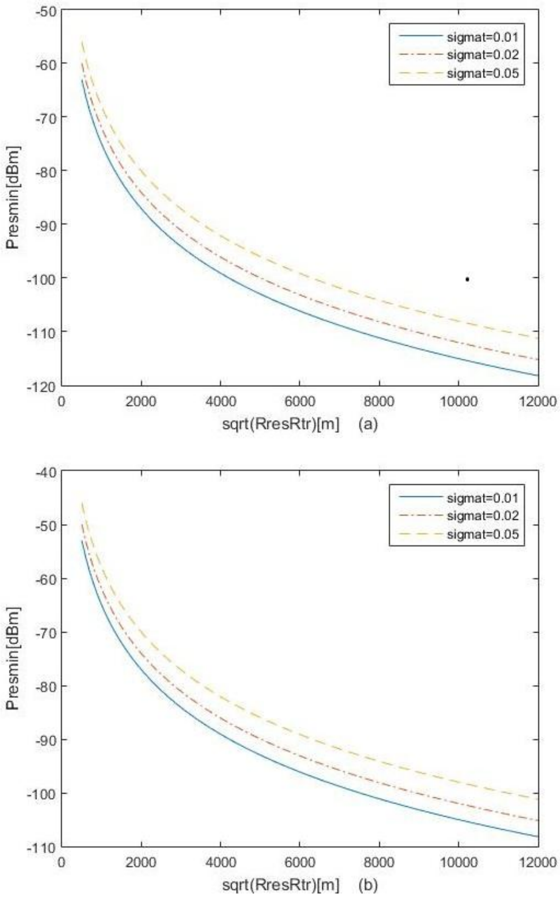

Fig. 2. Minimal power to detect target for T_{acc}=0.1 [s] a) and T_{acc}=1 [s] b)

The result in Fig. 2 show that it will be no easy to detect small, unmanned aircrafts with σ_t=0.01 m^2 with increasing bistatic operating distance. For distance $\sqrt{R_{tr}R_{res}} = 3000\ m$ and T_{acc}=0.1 s the value of P_{resmin}≈ -94 dBm which is not small, but it is possible because there are SDR systems that have more than (-115 dBm) for width of the spectrum of the signal 20 MHz.

According to the results in Fig.2 we can conclude that a much greater range of the bistatic radar than 3000 m can be achieved. But the solution of (3) for idealized space, where the influence of the ground surface and other losses factors for on the radar observation is neglected. The real one will be less than the calculated one and can be established experimentally for different real area.

Results for Δr from (4) are given in Fig. 3 for different values of r_{Σ}, α_r and B for ε_r=0. The obtained results are for a target moving perpendicular to the middle of the base and located from 100 to 1m respectively from the base. Analyzing (4) and the results for Δr and the coefficient α, it can be concluded that it depends strongly on the position of the target relative to base (B). Its value increases when approaching the base and has the smallest value at the extension of the base.

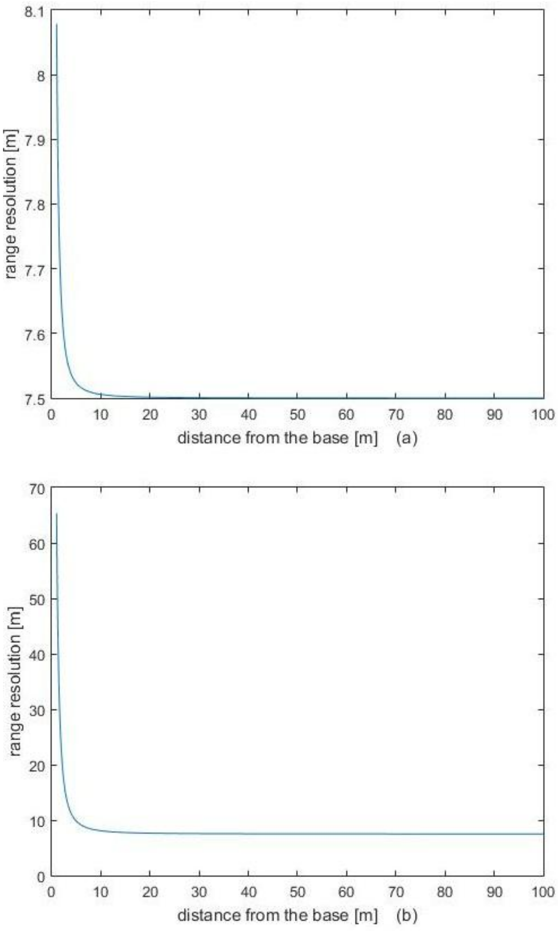

Fig. 3. Range resolution for B=100 [m] a) and B=1000 [m] b).

The potentially largest resolution of the bistatic radar is ΔR which for Δf=20 MHz is 7.5 meters.

In this case, it can be concluded that it is better from the point of view of obtaining better distance resolution to have a smaller distance between the receiver and the transmitter.

From (5) it can be concluded that the energy in the target channel is inversely proportional to the distance between the transmitter and the receiver and does not depend on the power radiated by the transmitter. Direct channel to target signal ratio is given in Fig. 4 for different values of B.

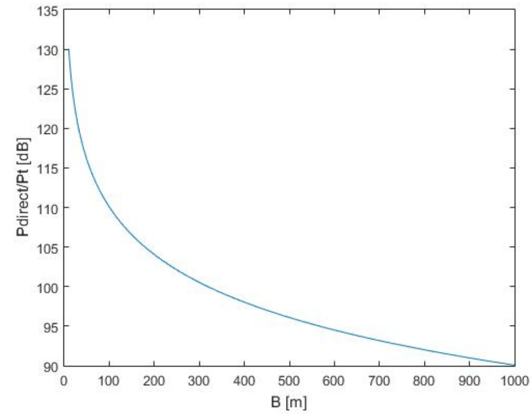

Fig. 4. Direct channel to target signal ratio.

The solution from (5) for η=0.01, σt=0.01 m2, $\sqrt{R_{tr}R_{res}} = 3000\ m.$, B=1000m, B=100m and B=10m is obtained approximately 90 dB, 110 dB and 130 dB respectively. This level of energy leaked from the side lobes is not small and usually various filters are used to suppress it on the target channel [3], [8]. In this case the Base need to be between 100 and 1000m so that it can be more reduced with filters direct channel to target signal ratio.

The conducted studies on the operating range, range resolution and direct channel to target signal ratio of a coherent bistatic pseudo-passive Wi-Fi radar show that it could fulfill the task of detecting the entry of a small unmanned aerial vehicle into the idealized protected area. However, for larger and different sized areas, more bistatic or multistatic radar systems will be needed, which will lead to an increase in the cost of the radar system for monitoring the area. For more accurate results, it is necessary to conduct a practical experiment with coherent bistatic Wi Fi radar and different sized targets in real areas of the area with different relief.

IV. Conclusions

In the paper results of theoretically potential capabilities on passive coherent Wi Fi radar are analysed. The result shows that coherent pseudo passive radar can be used in close distances for detecting unmanned small aerial vehicles for idealized area of protected object. The research conducted in this paper is the basis for beginning practical studies to detect the entry of unmanned aerial vehicles into a protected area.

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