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► **To cite this version:**

Stéphane Méric, Sylvain Azarian, Stéphane Lethimonier, Jean-Yves Baudais, Pierre Yves Jezequel, et al.. AMBRA project: cooperative multistatic radar for aerial target detection in urban areas. International conference radar, Société de l'électricité, de l'électronique et des technologies de l'information et de la communication, Oct 2024, Rennes, France. pp.1–6. hal-04760302

HAL Id: hal-04760302

<https://hal.science/hal-04760302v1>

Submitted on 30 Oct 2024

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AMBRA project: cooperative multistatic radar for aerial target detection in urban areas

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Abstract—Surveillance of low-altitude airspace in urban areas raises a number of challenges: the size of the areas to be monitored, the presence of buildings that can mask certain parts of the city, the terrain and the difficulty of identifying sites with sufficient clearance make it difficult to use conventional radars. Recent years have seen the emergence and rapid growth in the use of remote-controlled or autonomous drones equipped with control systems that enable them to fly at low altitude and low speed. Numerous solutions have been proposed for detecting them in open areas, but there are still few effective means of detecting them in urban areas. This difficulty will be even greater in the “city of the future”, when we want to detect autonomous delivery drones or “flying taxi” projects proposed to relieve urban road traffic congestion. The AMBRA (Active Multistatic Broadcast Radar) project proposes a new approach based on an existing infrastructure that is already capable of covering the entire urban area.

Index Terms—multistatic radar, broadcast, DVB-T2, drones, urban areas, low altitude, data fusion

I. INTRODUCTION

One way of meeting the challenges of detecting drones in an urban environment is to deploy a network of radars (monostatic or multistatic) to cover the entire city. These different radars are then interconnected and merge their data, making it possible to offer a centralised management system for surveillance and coordination of urban airspace. How can we ensure coverage of the whole area and how can we merge the data?

In that way, TDF, ENSENSYS, IETR and SDR-Technologies have joined forces to address these issues by proposing the AMBRA (Active Multistatic Broadcast Radar) project, funded by the French Defence Innovation Agency (AID) as part of the RAPID program. The AMBRA project is based on an original approach devised by TDF: exploiting a

feature of the DVB-T2 standard to transmit -without disrupting the original broadcast- a set of signals suitable for radar processing from a standard television broadcast transmitter. This solution makes it possible to use existing high-power installations (for example, several hundred kilowatts of EIRP in Paris from the Eiffel Tower), which are ideally placed and already capable of covering all urban areas for TV broadcasting.

The AMBRA project differs from DVB-T passive radar systems on one major point: the signal used for the radar function is selected and inserted periodically at precise times and can be modified at any time to adapt to the situation. The various receivers therefore know all the characteristics of the transmitted signal, enabling radar processing to maximise the probability of detection.

In the first part of this paper, we present the main architecture of the AMBRA network, highlighting some of the innovations implemented to meet the challenges of detecting aerial targets in urban areas. In particular, we look at the “radar system” aspects and the trade-off required to ensure that the remote broadcasting system operates correctly. In the second part, we look at the experimental validation system considering the waveforms we use, the methods adopted for sensor placement and the data fusion. Finally, we present the first results we obtained that validate our proof of concept.

II. AMBRA ARCHITECTURE

The AMBRA system is a multistatic radar system which is divided into three sub-system:

- The DVB-T2 transmission system, which adds signals either useful to the TV programme and to the radar processing,
- A network of receivers at the first step of radar processing,

Authors thank the French Defence Innovation Agency (AID) for their helpful funding support.

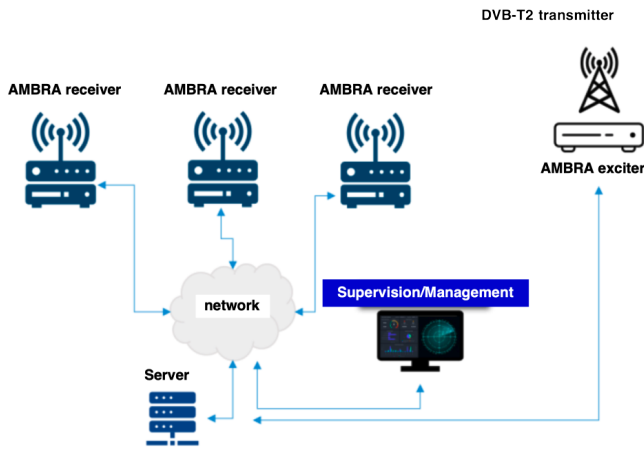


Fig. 1: AMBRA architecture.

- A supervision and data fusion system, which detects and then tracks the targets detected.

The network architecture is described in Fig. 1

A. AMBRA transmitter

The AMBRA transmission system must insert the signal chosen for radar processing into the digital TV data stream as defined by the standard. There are several points to consider at this step:

- Compliance with the required transmission masks (average power and side lobes),
- The peak power compatible with the power amplifiers constraints,
- Signal timing compatible with radar processing (integration time and repetition period).

The DVB-T2 standard defines the various characteristics of television stream: the data to be transmitted (audio, high-definition video, programs, etc.) are organised into physical frame structure [1]. These frame structures are organised into superframes, T2-frame, future extended frame (FEF), and OFDM symbols with cyclic-prefix guard intervals. Each superframe carries at most 255 T2-frames, and may also carry at most 255 FEF. The maximal length of these T2-frames and FEF is 250 ms each, and each of these frames starts with a specific OFDM symbol called P1. An overview of the frame and time structure of the DVB-T2 stream is shown in Fig. 2. The process patented by TDF [2] exploits an option provided by the FEF, which is used for radar detection. The Fig. 2 also shows an example of frequency modulated continuous wave chirps inserted after the P1 symbol. The choice of the LFM transmitted waveform is motivated by the simple way for implementing and processing first results as a proof of concept. This aspect will be addressed for further works. A typical RADAR signal configuration included into the FEF frame is given below (Table I): It should be noted that the system can change waveforms on demand, distribute different waveforms to different transmitters or transmit several waveforms simultaneously on several frequencies.

TABLE I: Signal configuration example

Data	Value
Sampling Frequency	64/7 MHz \approx 9.142 MHz
Wave type	FMCW
Number of Samples	16384
Number of repetitions	64
Silence slot time between P1 and signal beginning	$(128 + 64 \times 16384) \times 7/64 \mu\text{s}$ \approx 114.7 ms

The benefits of the multi-channel configuration are currently being studied in order to estimate the system's performance gains. However, this study seems to show that synchronous transmission of waveforms is fairly difficult to implement in the multi-channel case.

Another significant advantage of using existing television broadcasting infrastructures lies in the control and knowledge of the effective radiation pattern of the installations: numerous simulations and measurement campaigns have enabled precise mapping of the electric field received -at different heights- for each channel broadcast. This knowledge can be used to help in planning the placement of sensors in order to optimise radar coverage.

The Fig. 3 shows an example of coverage near the *Stade de France*, at a height of 30 metres for the Eiffel Tower transmitter.

B. Receivers network

A study has been carried out to optimise the position of receivers in a given operational context [3]. This position is conditioned by, among other things, the signal-to-noise ratio required to detect a target and by the probability of false alarm. This study was carried out for targets with a radar cross section (RCS) of less than 0 dBm². Depending on the minimum RCS to be detected, the orientation of the transmitter with respect to the area to be covered, we distribute the sensors so that the detectability threshold is guaranteed for several receivers. This method is applied with two sensors for the area of the Stade de France to be monitored (Fig. 4). All the results we obtained through signal processing i.e. number of receivers and angular positions, are largely described in [3].

Each radar receiver consists of two sub-assemblies:

- 1) A "front-end" unit that continuously digitises the RF stream and detects the presence of a FEF frame in the DVB-T2 stream;
- 2) A signal processing block responsible for isolating the useful sequence, pre-processing it and sending it to the data fusion system.

Various approaches are studied to divide the processing between the 'receiver' and 'data fusion' sub-systems:

- Processing up to detection by each sensor and sending metadata ('plots') for fusion,
- Sending raw data and centralising calculations.

As shown in Fig. 5, the pre-processing carried out by the sensor is currently restricted to the filtering and synchronisation functions: when the time sequence corresponding to the radar

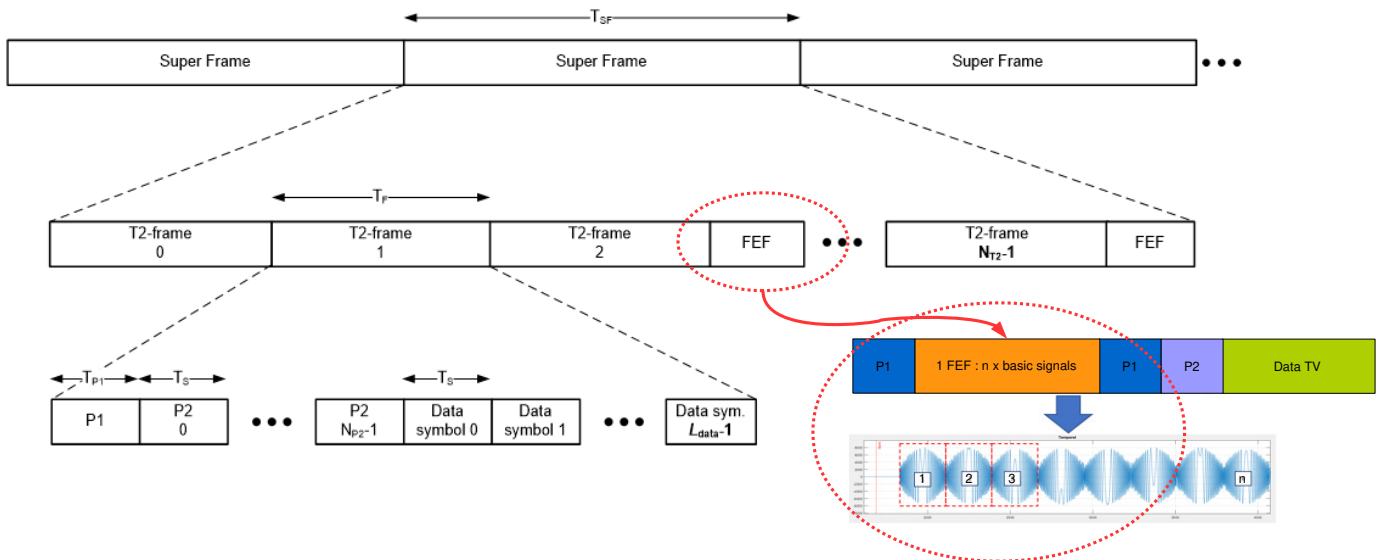


Fig. 2: DVBT-2 frames description and a FMCW signal inserted in a DVBT-2 frame.

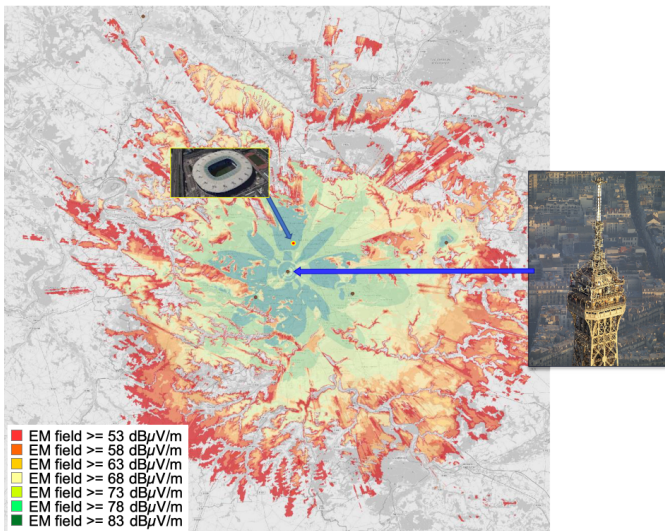


Fig. 3: Radio coverage near the Stade de France.

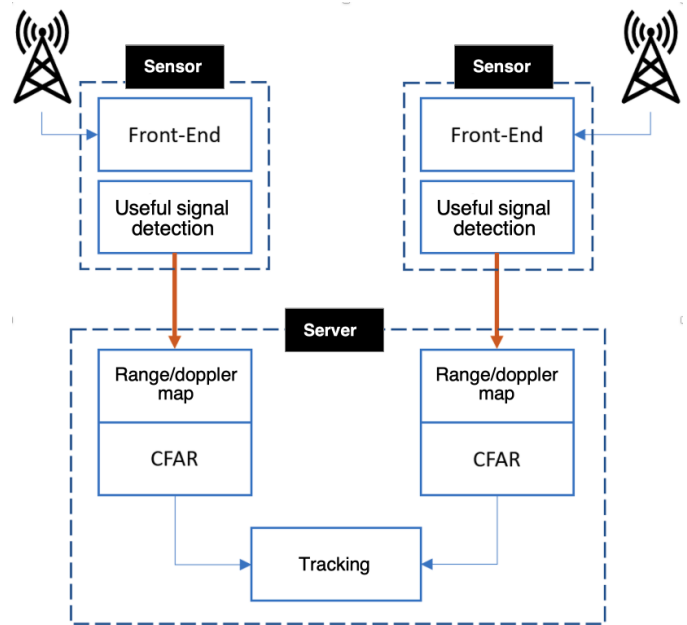


Fig. 5: System architecture.

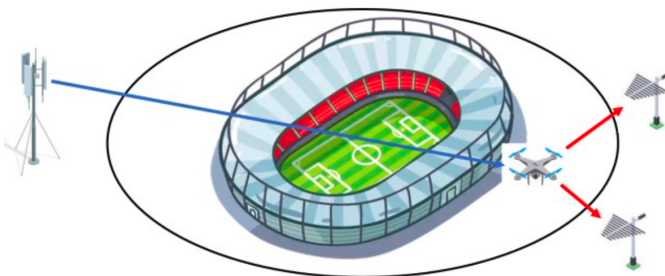


Fig. 4: Receiver and transmitter placement.

signal emitted is identified in the digitised stream, it is sent via a TCP/IP link to the central system. Given the current timing, all the calculation and data transfer operations must be carried out in less than 200 ms.

This approach is chosen because it makes the development process more simple (all the useful data is available in the same place), but it does not prefigure the final configuration: for a large number of sensors, it is certainly wiser to carry out the radar processing stages before sending the data, in order to limit bandwidth and computing power requirements.



Fig. 6: Particle tracking filter simulation considering 1 target around the *Stade de France*. The black lines are potential considered trajectories, the pink line is the final chosen trajectory and the purple line is corresponding to the particle filter results. These simulations are processed with 2 receivers.

C. Data fusion

A CFAR detector [4] is used to identify all the Range-Doppler boxes with a potential target. As a result of this step, each CFAR detector produces a list providing the bistatic range, the bistatic velocity and the intensity. In dense urban areas, particularly where roads are directly illuminated by the DVB-T2 transmission, a large number of targets are expected at the end of this stage. These various potential targets are then sent to a particle filtering algorithm [5] which is responsible for rejecting the least likely targets and consolidating the trajectories of the various targets moving in the monitored zone. Particle filtering is currently implemented for a single target and will have to be extended to the multi-target case. Fig. 6 shows an example of a tracking simulation carried out around the *Stade de France*.

III. FIRST EXPERIMENTAL RESULTS

Experimental validation of the system is currently underway on the IETR's MERISE (Monterfil station for radio and remote sensing) measurement station (Fig. 7).

Authorisation to transmit DVB-T2 is obtained from AR-COM (the French regulatory authority for radio transmission), enabling a standard TV signal to be transmitted to the test site. On this test site, a network of 4 AMBRA sensors is deployed respecting the study described in [3] and connected via a TCP-IP network to a server responsible for consolidating radar measurements for the detection of DJI Matrice UAVs.

A. ULM (Ultra-Light Motorized plane) detection

In order to validate the entire processing chain, we carry out an initial measurement on an object that is a priori easy to detect because it is large and has high Doppler during the experiment: the IETR's PIMA plane (Fig.8a). In Fig. 8b, we can clearly see the echo corresponding to the passage of the PIMA plane through the zone monitored by the 4 receivers both in distance and in Doppler. At this stage, the detection principle and the entire AMBRA network (transmitter, receiver network, insertion of a FEF) are validated on this example.

B. UAV detection

To address a use case, we then choose to apply the concept with a drone flying over the area (Fig. 9a). For this experiment, we can indicate that the configuration of the site does not allow us to have a drone speed high enough to have a drone signature far enough from the ground clutter (Fig. 9b). In addition, the drone's backscatter level is not high enough to extract itself from the ground clutter. On the other hand, the signature of the drone's blades seems to stand out very clearly in order to identify the presence of the drone.

Given the current state of the results, it is not possible to carry out effective tracking operations without being able to clearly identify the drone's position (distance and Doppler). The proposal is therefore to adapt a FEF signal that will maximise the signal-to-clutter-to-noise ratio.

IV. CONCLUSIONS AND FURTHER WORKS

The AMBRA project proposes drone detection based on a collaborative multistatic radar system. The multistatic aspect is linked to the presence of a transmitter (a DVB-T2 transmission unit) and several receivers designed to monitor the area of interest. The collaborative characteristic is linked to the part of the transmitted signal known by the receivers to improve the performance of passive detection based on DVBT-type signals. The project brings together complementary skills ranging from waveform analysis to the production of DVBT2 receivers and the implementation of a decision strategy. One of the first tasks is dedicated to design a better suited transmitted waveform inside the FEF instead of the FMCW one. As the project progresses, in parallel with the study of waveforms, experiments will be carried out at the MERISE site, using initial measurements of DVBT2 signals returned by microlights and drones to validate the detectability of these flying objects. Considering the low RCS of UAV and the low velocity of UAV, specific and adaptative filters will be considered. To design these filters, we plan to take into account the micro-doppler signature induced by the UAV blade rotation. In addition to the studies carried out on the choice of an efficient waveform to maximise drone detection, a multi-channel extension is envisaged to improve the resolution in terms of range and speed of the AMBRA system.

ACKNOWLEDGMENT

The project partners would like to thank the *Agence Innovation Défense* (AID) and the *Direction Générale de l'Armement* (DGA) for their support through the RAPID AMBRA project.

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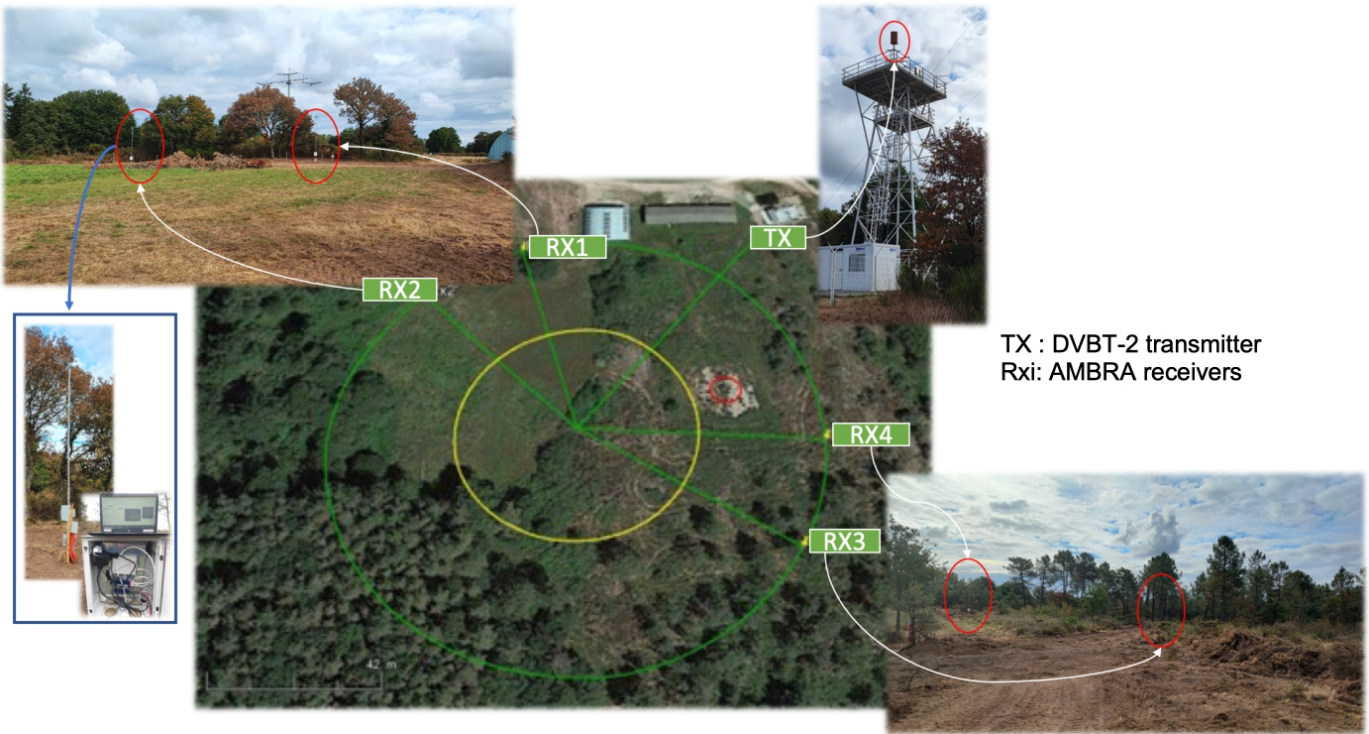
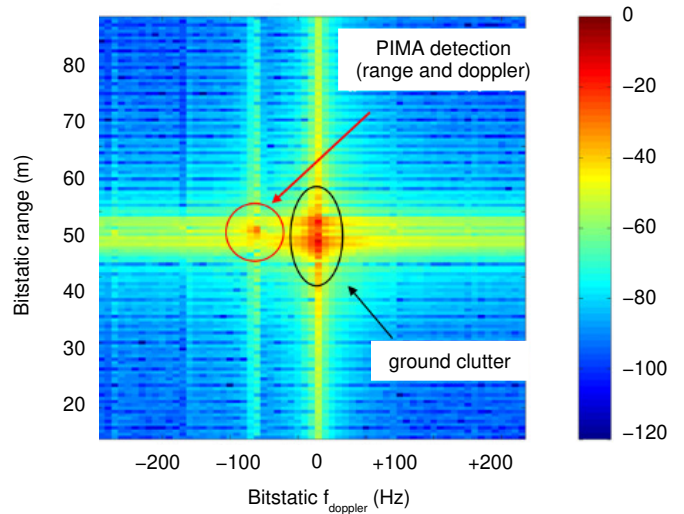


Fig. 7: Deployment on the Monterfil site (MERISE) for the AMBRA experiment.



(a) PIMA plane.

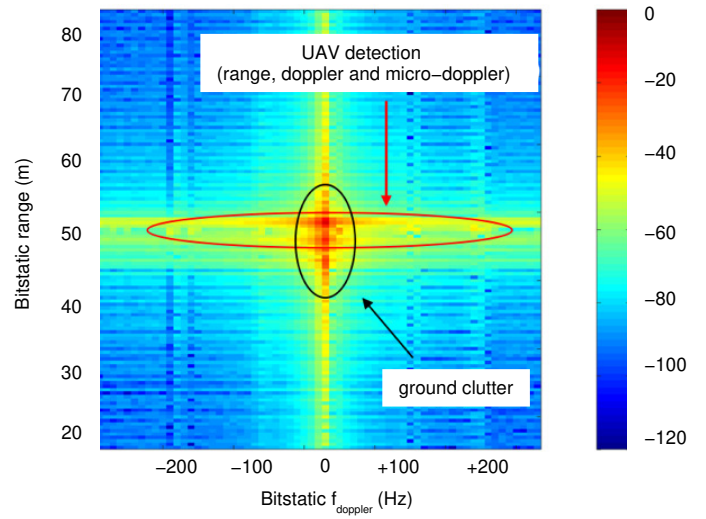


(b) Range-Doppler map of the PIMA plane.

Fig. 8: Results of the AMBRA experiment with the PIMA plane.



(a) Drone DJI matrice 300



(b) Drone DJI Matrice 300 *range-doppler* map.

Fig. 9: Results of the AMBRA experiment with the drone DJI Matrice 300.

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