Ad hoc receive sensors aimed at enhancing multistatic radar operation for surveillance of limited critical areas.

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***Abstract* – Possible advances of multistatic radar systems are considered for surveillance of limited and critical areas for homeland protection. New enabling technologies are highlighted by referring to the use of multiparametric multichannel multistatic radar receivers densely distributed over the area of interest. In such a framework, specific focus is given to evaluating target visibility as well as to the possible application of an "Ad Hoc" Network (AHN) of smart and adaptive radar-communication antennas.**

1 INTRODUCTION

A dense network of passive receiver sensors can be adopted to exploit enhanced multistatic radar sensing in limited critical areas [1,2]. Such a multistatic radar configuration can be used to extend spatial coverage and enhance local area performance of monostatic radars acting for surveillance over large areas. In the latter case, transmission by monostatic radars can also be used as target illumination for multistatic radar sensing. However, appropriately designed illuminators and/or already existing broadcasting systems (e.g. radio and TV stations) can alternatively be adopted for multistatic radar sensing, even without monostatic radar capabilities.

Our analysis considers the above type of multistatic radar sensing system and mainly addresses configurations suitable for application to homeland protection of urban-metropolitan areas from air-vehicle threats. Specifically, this analysis refers to a system within the following framework of capabilities and features:

– use of a dense network of passive sensors, acting as multistatic radar receivers, within the area under surveillance;
– use of appropriately designed illuminators to allow optimum multistatic radar operation over the same area, even without monostatic radar capability;
– limitation of the scan time and increase of the observation continuity, if needed, by reducing antenna directivity for target illumination as much as this is compatible with target detection recovery (made possible by the dense network of passive multistatic sensors); and,
– joint use of multiple differently located illuminators, which provide different space coverage and, if needed, adopt frequency & signal diversity to enhance target observation capabilities.

Through this paper, some contributions are made towards assessment of configuration and capabilities of such a multistatic radar system. Some highlights are made on a simulation tool (whose development is in progress) for evaluating target visibility by such a system in given homeland protection application scenarios. Finally, the use of smart and adaptive antennas in an *ad-hoc* network of multistatic receive stations is discussed.

2 ENABLING TECHNOLOGIES

In this multistatic radar system, we envision an increasing role played by the exploitation of multiplatform / multichannel / multidimensional sensing capability of the ad-hoc network of passive sensors (receive – only stations). This is also in agreement with reasoning, efforts and results of recent research activities focused on such capabilities in radar and communication systems [3]REF.

Wide multistatic sensing is expected to significantly improve target detection, due to variations of multistatic target cross-section along different re-radiation angles associated with the multistatic receiver positions. Furthermore, "Receiver Multichannel /Multidimensional sensing capability" is extensively anticipated for each receiving multistatic station. This is linked to the following capabilities, which should be used, as needed, to improve target detection, resolution, localization and classification:

– simultaneous dual polarization reception;
– three channel field reception through three - dimensional e.m. antenna feeding to allow both polarization and angle of arrival sensing of the impinging e.m. field;
– multibeam and/or electronic scanning antenna in reception ;
– Doppler frequency sensing ;
– time delay sensing and resolution (dependent on the type of transmitted waveform);
– multifrequency reception (dependent on frequency diversity adopted by the target illuminators); and,
– dual polarization in transmission.

The overall system performance is also related to the exploitation of enhanced technologies to enable additional capabilities, such as:

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– more efficient and flexible solutions for synchronous and coherent signal reception and processing by the multistatic receivers;
– efficient solutions for fusion of the data provided by the multistatic receivers;
– optimization of the illuminators configuration and operation, for optimum coverage of the area under surveillance, through static or dynamic multibeam and/or multifrequency radiation;
– automatic dynamic coordination and cooperation among the multistatic system components; and,
– optimum solution for network communications among the multistatic system components.

Obviously, large exploitation of the above capabilities implies a noticeable increase of system complexity. However, due to current and anticipated rapid technology advancements, technical and economic affordability of such complexity is becoming continuously more viable for receive – only stations. These are indeed the main components of the proposed system, actually conceived as a sort of network of *ad-hoc* sensors/receivers. New materials and technologies allow to build compact and flexible broadband full-scan coverage conformal array antennas, especially when used for reception only. Availability of fully developed MMIC technologies, to build microwave and radiofrequency circuits and devices, makes also more feasible and less expensive to implement highly integrated complex receive–only stations for multichannel reception. Furthermore, embedded fast computing devices are enabling continuous increase of digital signal and data processing capability, through compact subsystems, which therefore can be exploited for parallel multichannel signal reception and processing in each multistatic station. An example where some of these technological features are merged is the Advanced Multifunction Radio Frequency Concept (AMRFC) program [6].

3 TARGET MULTISTATIC VISIBILITY

A main concern is to assess target visibility in the surveillance area of interest, through the proposed multistatic radar system, as needed for high performance of target detection, location and tracking. A simulation tool is under development to support system performance evaluation with synthetic targets, while the use of models of real targets of interest is also anticipated. At present, specific features of such a simulator are:

- uniform distribution of the receivers along a spiral over a pre-set area (circular symmetry is thus obtained to make both performance and its evaluation less sensitive to the orientation of the target trajectory with respect to the surveilled area);
- relating target detectability (in the clear) to the number of receivers which meet conditions for autonomous target detection by each of them;
- relating target location to the spread of target of angular position with respect to those multistatic receivers actually detecting the target (this feature is linked to multistatic performance of locating targets); and,
- use of a single target illuminator which can be arbitrarily located.

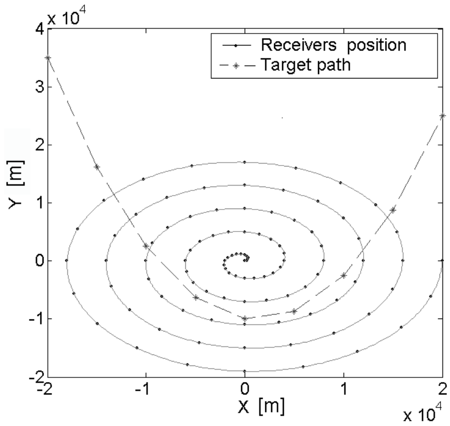

Figure 1: Position of 100 receivers along a spiral inside an area of 20 x 20 km^2 and ground projection of the target trajectory.

To evaluate the simulator's performance, reference is made to a "power visibility parameter" that is a normalized value of the received power $P_{R,i}$ at the i-th receiver, given by the bistatic radar equation:

$$P_{R,i} = \frac{P_T G_{T,i} G_{R,i} \lambda^2 \sigma_{b,i}}{(4\pi)^3 R_T^2 R_{R,i}^2} \tag{1}$$

where P_T is the transmitted power, $G_{T,i}$ and $G_{R,i}$ the antenna gains in transmission and reception with respect to the i-th receiver, R_T the transmitter-target distance, $R_{R,i}$ the target-receiver distance, λ the wavelength and $\sigma_{b,i}$ the bistatic target radar cross section depending on two angles of view between transmitter and target (elevation and azimuth) and two angles of view between target and i-th receiver (elevation and azimuth). Normalizing (1) with respect to the radiation's parameters, P_T $G_{T,i}$ and $G_{R,i}$ we obtain the visibility parameter $P_{v,i}$ at the i-th receiver, depending only on physical target parameters, defined as:

$$P_{V,i} = \frac{\lambda^2 \sigma_{b,i}}{(4\pi)^3 R_T^2 R_{R,i}^2} \tag{2}$$

The sensitivity of the monostatic radar receiver is to be accounted for to derive the signal to noise ratio SNR_i, at the i-th receiver, from $P_{R,i}$. The $P_{R,i}$ threshold for target detection with a set probability, has to be related to the *SNR* value actually determining that target detectability. The corresponding $P_{v,i}$ threshold depends on the factors of its normalization with respect to $P_{R,i}$. Some sample simulation results are reported below which refer to: i) an area under surveillance with an extension of 40x40 km^2; ii) a single transmitter located 30 km out of this area; iii) a set of 100 receivers arranged and uniformly distributed within the area following a spiral path as indicated in Fig. 1; and, iv) a target at constant height of 1 Km from the ground, along the pre-set trajectory shown in Fig. 1. The results reported in this section refer to an artificial target characterized by a constant σ_b pattern, while moving along its trajectory (i.e. keeping constant altitude of flight for an airplane), as well as by two directions of maximum radiation toward the ground.

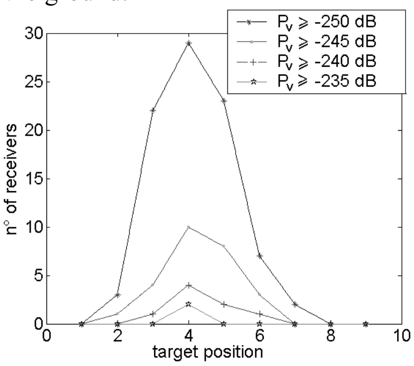

Fig. 2 - Number of receivers exceeding the target visibility threshold, assuming receiver location shown in Fig. 1

This implies that changes of the scattering properties during the motion is only due to the movement of the target with respect to the positions of the transmitter and the receivers. The $\sigma_{b,i}$ pattern thus obtained shows a dynamic range of [-30, 0] dBsm on the whole solid angle domain. We also suppose that the transmission frequency is 6 GHz. Under the assumption that the target moves along the trajectory of Fig. 1, computations show that $P_{V,i}$ varies between -250 and –235 dB within the area under surveillance. For nine different positions of the target, selected as shown in Fig. 1, we also computed the number of receivers that exceed the prefixed target visibility thresholds for $P_{V,i}$, as reported in Fig. 2. This figure shows the results obtained with such analysis considering four different values of threshold of $P_{V,i}$ (from –250 to –235 dB with 5dB step). Notice that the target position #4 is that with the greater target visibility. Fig. 3 shows the position of the receivers where $P_{V,i}$ is greater than –240 dB threshold for such a target position. Assuming P_T=80 dBm, G_T=20 dB and G_R=15 dB a visibility of -240 dB gives a peak received power of –125 dBm.

With such a peak received power, an *SNR* of 15 dB at the output of a matched filter, assuming a system temperature of 400 K, can be achieved with an equivalent pulse duration of about 0.5 ms.

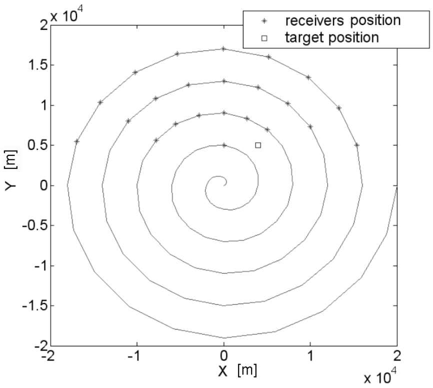

Figure 3: Receivers (black dots) where P_v is greater than –240 dB when the target is at the fourth position of the trajectory (square marker)

4 ANTENNAS FOR THE AD HOC RECEIVE SENSORS

The system of receiving sensors we propose for the multistatic radar is based on a “Ad Hoc” Network (AHN), where each element of the network performs both as radar receive sensor and as a communication node. Network nodes can be randomly distributed on the surveillance area. The position of the target is not known a-priori. Therefore, we consider it to be useful that each node is equipped with a smart or adaptive antenna.

In principle smart antennas can enhance the capacity and quality of systems by fully exploiting the spatial dimension through space division multiple access (SDMA), a way of tracking and separating by angle users or systems sharing the same communications channel thanks to directive patterns, and diversity techniques. A smart conformal array capable of hemispherical coverage represents the optimal choice for the proposed system, provided that its mechanical and electrical complexity be compatible with the overall cost constraints.

For reasons of mechanical simplicity and integrability, we have restricted ourselves to consider conformal phased arrays with a hemispherical element disposition only [4]. Two classes of possible element arrangements capable of providing almost uniform beam scanning can alternatively be derived by i) placing the radiating elements at the vertices of some canonical polyhedra; and, ii) randomly dispersing the radiating elements on the surface of a sphere with uniform spatial density. In both pseudo-uniform and pseudo-random configurations the advantage of polarization agility and broad band operation is achieved by using circularly polarized elements, such as spiral antennas, which are known for their ability to produce very wide band, almost perfectly circular polarized radiation [5]. Thus, the two components of the total far field radiated from the array can be phased in turn without distinction and the array is expected to have good performance in both polarizations for all scan angles of interest.

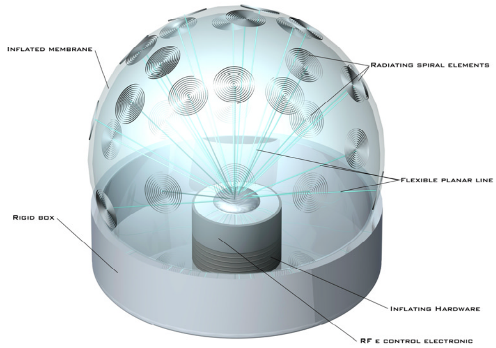

Fig. 4 – Conceptual view of a receiver with spiral antennas disposed on a spherical structure.

Randomly distributed elements, conceptually shown in Fig. 4, are preferable for radar applications because the non-periodic arrangement eliminates grating lobes and results in an average side lobe level that is inversely proportional to the number of elements. Moreover, on account of the cancellation of grating lobes, the array can take full advantage of the broad band radiating elements. Radiation pattern estimates of a 32 element spherical conformal array are shown in Fig. 5. The real-time tracking capability of the proposed antenna can be fully exploited using a MIMIC based phase shifter module for each radiating element, because multiple beams can be simultaneously synthesized in real time during the reception of the scattered return of the target or of the signal transmitted from a network node. Finally, the complexity of the antenna can be greatly reduced if beam scanning is performed only during reception and transmission is separately accomplished by an omni directional auxiliary antenna.

4 CONCLUDING REMARKS

This preliminary analysis represents a first contribution to devise and assess performance of the proposed multistatic radar system.

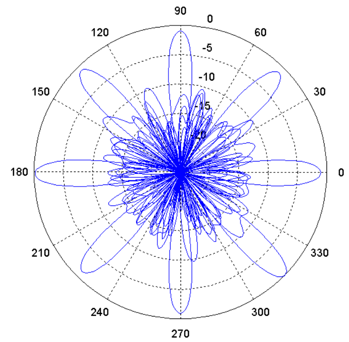

Fig. 5 - Radiation patterns of a 32 element spherical conformal array

Currently, research is in progress to perform a high level system analysis to focus on system configuration and feasibility in order to highlight research priority to achieve optimum definition of architecture, design, as well as performance evaluation of such a type of system. This analysis is also related to research efforts currently sponsored by the United States Department of Defense under an AFOSR/MURI grant FA9550-05-1-0443 and a DARPA/NRL grant N00173-06-1-G006.

5 BIBLIOGRAPHY

[1] Bradaric, I.; Capraro, G.T.; Weiner, D.D.; Wicks, M.C., “Multistatic radar systems signal processing”, *2006 IEEE Conference on Radar*, 24-27 April 2006, p. 8.

[2] Doughty, S.; Woodbridge, K.; Baker, C., ”Characterisation of a Multistatic Radar System”, *3rd European Radar Conference*, Sept. 2006, pp.5-8.

[3]Mendelson, H., ”An alternative approach to multichannel radar detection and location,” *2005 IEEE Aerospace Conference*, 5-12 March 2005, pp. 2212 – 2221.

[4] A. Vallecchi and G. Biffi Gentili, “Broad band full scan coverage dual polarised spherical conformal phased array,” *J. Electromagn. Waves Appl.*, vol. 16, Mar. 2002. pp. 385–401.

[5] Vallecchi and G. Biffi Gentili, “Broad band full scan coverage polarization agile spherical conformal array antennas: pseudo-uniform vs. pseudo-random element arrangements,” *2003 IEEE International Symposium on Phased Array Systems and Technology*, Oct. 14-17, 2003, Boston, Massachusetts.

[6] Tavik et al.,” The Advanced Multifunction RF Concept”, *IEEE Trans. Microw. Theory Tech.,” Vol. 50(3)*, Mar. 2005, pp. 1009-1020.