TARGET MODEL EFFECTS ON MIMO RADAR PERFORMANCE

P.F. Sammartino, C.J. Baker*, H.D. Griffiths**

**Department of Electronic and Electrical Engineering, University College, London, WC1E 7JE, UK*

{p.sammartino, c.baker, h.griffiths}@ee.ucl.ac.uk

ABSTRACT

A simple comparison between “spatial MIMO” (Multiple Input – Multiple Output), “frequency MIMO” and coherent netted radar systems shows that better performance can be achieved by the incoherent processing approaches. This assumes that the MIMO techniques acquire independent samples and there is no a-priori information available to the netted radar enabling the incoming signals to be phase-aligned [1]. Here we consider a more detailed model for target backscatter in order to gain a deeper sight into the true potential of these radar signal processing techniques. The overall aim of this work is to understand the performances available when real targets are under surveillance and to understand which conditions make MIMO perform best or, at least, better than a netted radar system. The target models introduced here are a step towards this aim.

1. INTRODUCTION

The improvement of performance achieved introducing a MIMO system has been widely reported in the communication literature. A similar approach to signal processing has been studied for radar systems. Two kinds of MIMO radar systems have been developed: the first one is characterized by multiple antennas transmitting and/or receiving far away each other so that it can exploit effects such as target scintillation. This is usually called “spatial MIMO” or simply MIMO and takes advantage of the response of a target illuminated by signals with different carrier frequencies transmitted by co-located antennas; this has been called “frequency MIMO”.

Both these systems process the incoming signals in an incoherent way [2]. They have also been compared to a netted radar system operating coherently. Results in [1] show that MIMO systems have higher performance than the netted radar when the signals are processed without particular and dedicated algorithms for aligning the phases, that means that this performance can be achieved with an incoherent processing, i.e. with a relatively simple structure of the receiver and is potentially a valuable advantage. In the case of re-phasing the signals before processing (re-phased netted radar), that is expected to perform the best as it makes the signals to cohere constructively (thus maximizing the signal-to-noise ratio), MIMO systems have been shown to have a loss of only few dBs on the performances ([1]).

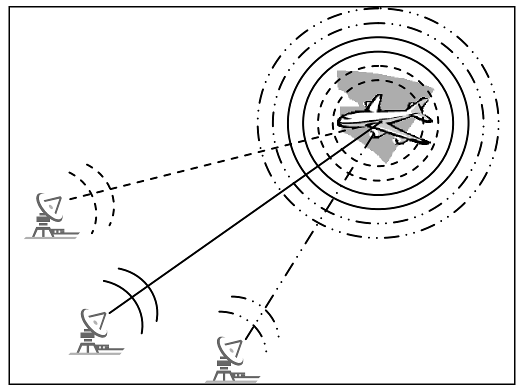

Fig. 1: spatial MIMO and netted radar configuration

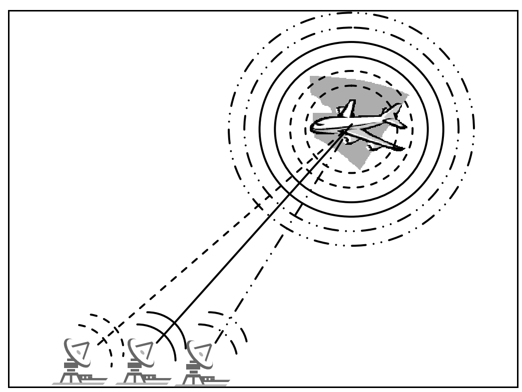

Fig. 2: frequency MIMO configuration

2. MIMO CONCEPTS AND TARGET MODELS

The MIMO concept can be applied to radar in a number of ways. For example, the full effects of spatial diversity can be exploited by multiple locations of transmitters and receivers that give rise to the necessary independent angular samples. Alternatively separate frequencies can illuminate a target from a common location and similarly enable the collection of independent samples of the target. Thirdly, the spatial MIMO configuration can process the data coherently as in a distributed radar system. Further, spatial, frequency, temporal waveform coding and polarisation diversity can be collectively combined. This should offer the most complete environment for gathering multidimensional radar data which, in turn, should lead to the most effective means of exploitation. Two immediate and significant potential benefits could be:

(i) Diversity can be used to separate scatterering centres from one another that otherwise cause glint signatures and
(ii) Diversity offers a means of separating targets from clutter in severely clutter limited detection scenarios.

In order to examine the performance of the three approaches a number of target representations have been used and described below.

2.1. Swerling III target

As this model does not depend on the transmitted frequency, only a comparison between the spatial MIMO and the netted radar has been produced. As known, the pdf of the RCS γ can be written as following:

$$p(\gamma) = 4\frac{\gamma}{\sigma^2}\exp\left\{-2\frac{\gamma}{\sigma}\right\}, \tag{1}$$

where σ is the expected value of the RCS distribution.

2.2. Rician distribution

Both spherical target and Swerling III RCS model can be considered a particular realization of this distribution. Under this assumption, a more realistic statistical model of the RCS of a target is expected to be described in this way. Also in this case a comparison between the only spatial MIMO and netted radar will be realized, as the main characteristics of this RCS model are independent from the carrier frequency. As known, the pdf of the RCS γ can be written as following:

$$p(\gamma) = \frac{\gamma}{\sigma^2}\exp\left\{-\frac{\gamma^2 + m^2}{2\sigma^2}\right\} I_0\left(\frac{\gamma m}{\sigma^2}\right), \tag{2}$$

where σ is the 2nd not centred moment of the RCS distribution and m is a parameter controlling its moments.

2.3. Spherical target

We considered a metallic spherical target. In this case the behaviour of the RCS, as function of the ratio between its radius r and the transmitted wavelength λ, is well known and is shown in Fig. 1. The results observed are particularly meaningful from a theoretical point of view, as it is particularly evident that there is a clear frequency dependence that will contribute to the performance of the differing approaches in different ways.

3. RESULTS

Here we highlight some of the results for the presented cases. When making a comparison of the performances, the same power has been supplied to the systems, even when transmitting different numbers of signals. All the curves presented have been achieved for a false alarm rate equal to 10^{-6}. Generally at first sight the results obtained in [1] seem to be confirmed: for noise-like targets both MIMO systems apparently offer superior performance to netted radar, because they are able to exploit spatial or frequency diversity and the incoherent processing that prevents coherent cancellation or attenuation of the returning echo. This is, of course, the main motivation behind the use of the MIMO technique. Furthermore MIMOs' performances are not so far from the re-phased netted radar's ones, that provides to the system the highest signal-to-noise ratio. More particularly:

3.1. Swerling III RCS model

Figure 3 and 4 show the results for spatial MIMO and netted radars against a Swerling III target respectively with 4 and 25 processed signals. Frequency MIMO is not reported as the RCS model is independent of the carrier frequency. Here it may be observed that the more spatial samples the better the resulting detection performance.

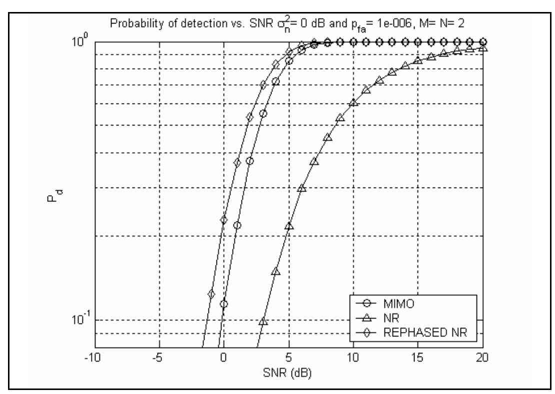

Fig. 3: Swerling III performances

The MIMO concept is seen to outperform the netted radar in all cases. Additionally, the transmitted power is a constant in all the systems. For the spatial MIMO the lower the number of processed signals the lower the achieved performance. This reinforces the conviction that it is possible to improve the capacity of detection of a radar system by looking to the target from an increasing number of different angles. However, this assumes that independent samples can always be taken. This may not be the cases when considering real targets and is partly examined by considering the sphere target.

Also note that for the netted case it is shown in Figures 3 and 4 that the performance decreases as the number of nodes increases. This may seem contrary to expectation but is explained by the increasing randomizing of the received signal phases with increasing number of independent looks.

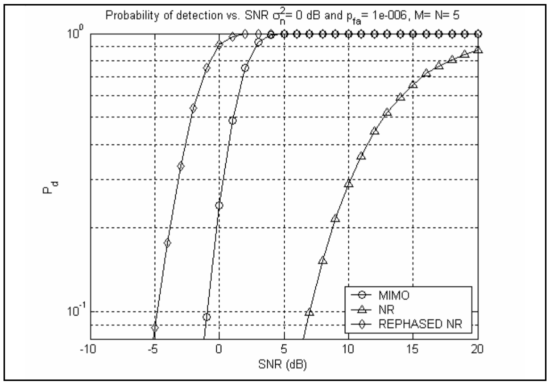

Fig. 4: Swerling III performances

3.2. Rician RCS model

Figures 5 and 6 show the results for a Rician distribution of the RCS for a particular value of the parameter *m* in the (2) and for 4 and 25 processed signals. This parameter controls the mean value and the variance of the PDF of the RCS, thus its performances.

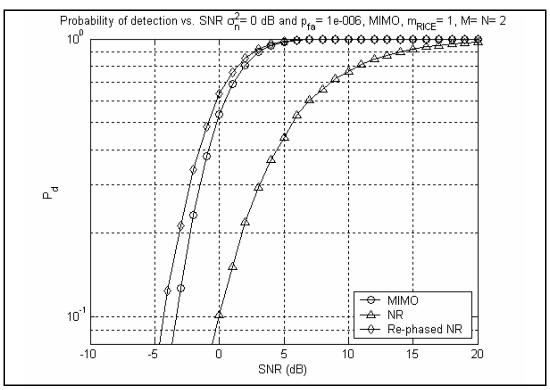

Fig. 5: Rician RCS performances

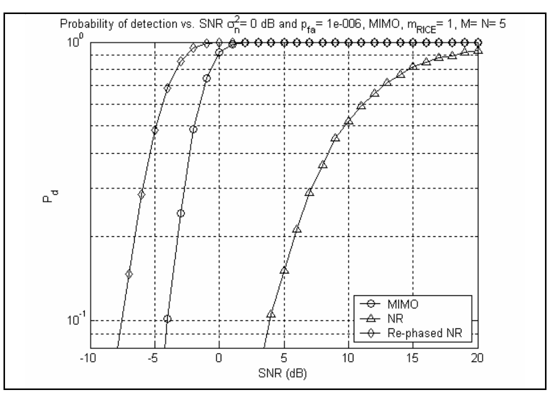

Fig. 6: Rician RCS performances

Again, as in all the previously examined RCS distribution, included the ones in [1], MIMO performance is not so far from the re-phased netted radar's.

3.3. Spherical RCS model

The spherical target doesn't yield independent samples for spatial MIMO but it does to a certain extent when the frequency variant is employed. Figures 10 and 11 indicate that it is not possible to predict the best performer a priori between the frequency and the spatial MIMO cases.

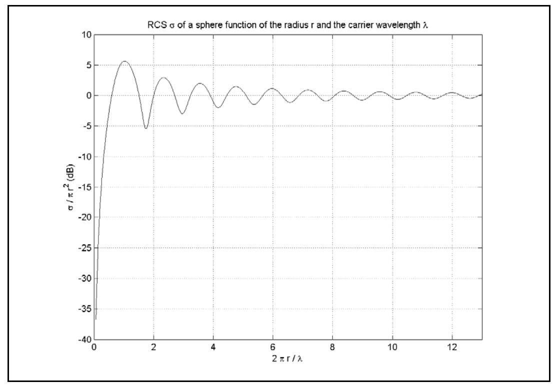

Fig. 7: RCS of a sphere

For the sake of simplicity the bistatic angle of reflection has been supposed to be not far from the monostatic one, so that the monostatic RCS is a good approximation of the measured one. Of course, as the monostatic RCS of a sphere is greater than every measured bistatic one at the same range and frequency, in a high-bistatic-angle configuration a loss in the performances of these systems is expected. In Figure 8 the performance achieved by frequency MIMO is even better than the one of the netted radar where an algorithm for re-phasing the received signals has also been applied. This is due to the frequency diversity permitting at least one measurement of the target's RCS in the resonance zone of the curve in Figure 7: that introduces some extra signal strength into the signal power, hence enhancing detection.

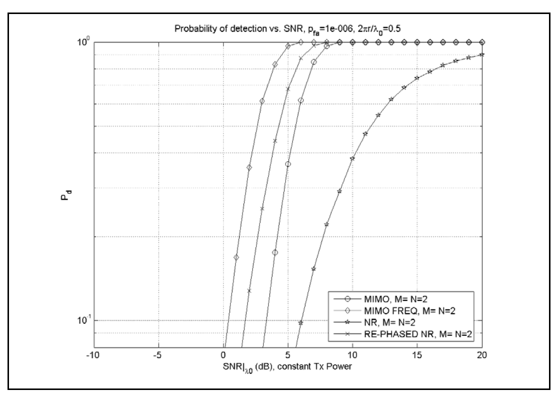

Fig. 8: Spherical target performances

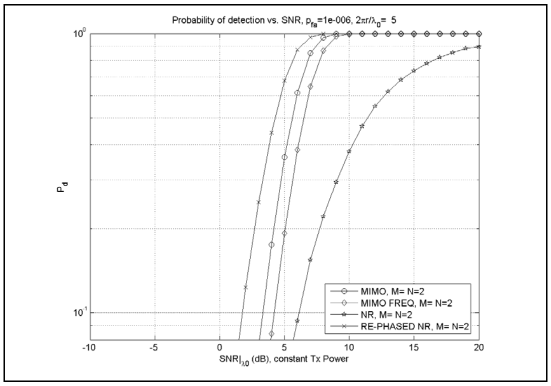

Fig. 9: Spherical target performances

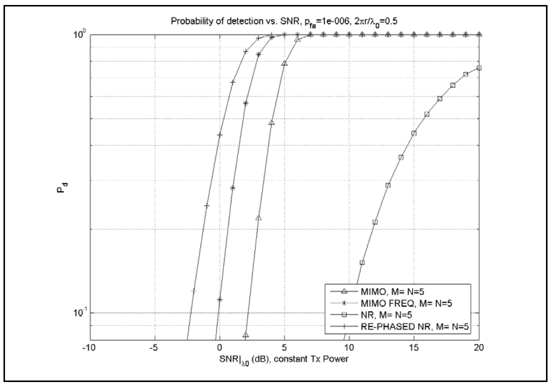

Fig. 10: Spherical target performances

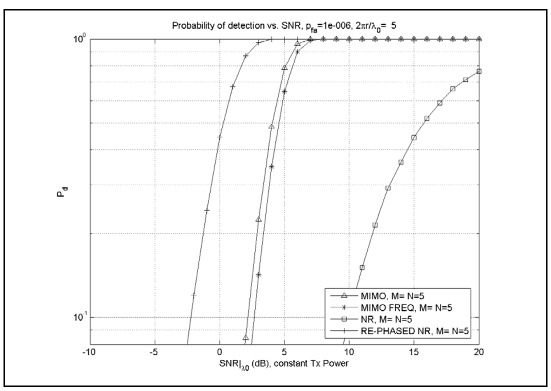

Fig. 11: Spherical target performances

The frequencies used for this form of MIMO radar system are linearly spaced between 1 and 5 GHz, while the carrier frequency of the other two radars is 3 GHz (λ_0= 10 cm). Thus the radii of the targets shown the figures are 5 or 50 cm. As soon as the ratio $2\pi r/\lambda$ reaches the optical zone of Figure 7, the frequency MIMO cannot exploit the extra signal strength so it performs worse than the re-phased netted radar. As expected, the spatial MIMO Pd curve always performs worse than the re-phased netted radar. In Figure 10 the resonance effect is still present and the high number of signals processed realizes an average between all the measurements of the RCS, so that the Pd curve performs worse than the re-phased netted radar one. Note that the reverse is true if the phasing is not done for the netted radar. Figure 11 shows clearly that in this case the MIMO performance approach each other as soon as the optical region is reached and many signals are taken into account.

4. DISCUSSION

Whilst the above results indicate the important relationships between achievable performance and target backscatter characteristics, they still embody simple assumptions that require more detailed investigation. The results obtained for Swerling III and Rician models are in line with [1] for a Swerling I model. This is a step toward the validation of a MIMO radar as a system able to replace a re-phased netted radar, whenever is acceptable to trade few dB on the total SNR with a simple structure of the detector. Frequency diversity has been shown to reach interesting results, as it overcomes under specific circumstances the theoretical upper bound limit of the re-phased netted radar. Thus, against real targets, a combination of spatial and frequency MIMO concept is expected to lead to the most exploitive use of diversity for detecting. Any model used in this paper will need to be tested in realistic conditions via full scale experimentation.

5. REFERENCES

[1] P.F. Sammartino, C.J. Baker, H.D. Griffiths – "A comparison of algorithms for MIMO and netted radar systems" – 2nd International Waveform Diversity & Design Conference, Lihue, Hawaii, 22 – 27 Jan 2006.

[2] E. Fishler, A. Hairmovich, R. Blum, D. Chizhik, L. Cimini, R. Valenzuela – "MIMO radar : an idea whose time has come" *Proc. IEEE Radar Conference 2004*, Philadelphia, USA, pp71-78, April 2004.

[3] K.W Forsythe, D.W. Bliss, G.S. Fawcett – "Multiple-input multiple-output (MIMO) radar: performance issues" – Record of the 38th Asilomar Conference, 2004, Volume 1 – pages: 310-315

[4] D.R. Fuhrmann; G. San Antonio – Transmit beamforming for MIMO radar systems using partial signal correlation – Record of the 38th Asilomar Conference, 2004, Volume 1, pages: 295 – 299.

[5] E.F. Knott, J.F. Shaeffer, M.T. Tuley – "Radar Cross Section" – Artech House, 1985

[6] M.I. Skolnik – "Introduction to radar systems" – McGraw Hill, 1981.

[7] L. V. Blake – "Radar Range-Performance Analysis" – Lexington Books, 1980.

[8] E. Fishler, A. Hairmovich, R. Blum, L. Cimini, D. Chizhik, R. Valenzuela – "Performance of MIMO radar systems: Advantages of angular diversity" – Conference Record of the 38th Asilomar Conference on Signals, Systems and Computers, vol. 1, pp. 305-309, Pacific Grove, CA, Nov. 2004.

[9] E. Fishler, A. Hairmovich, R. Blum, L. Cimini, D. Chizhik, R. Valenzuela – "Spatial diversity in radars – Models and detection performance" – Signals, Systems and Computers, 2004. Conference Record of the 38th Asilomar Conference on Volume 1, 7-10 Nov. 2004 Page(s):305 - 309 Vol.1

[10] F.C. Robey, S. Coutts, D. Weikle, J.C. McHarg, K.Cuomo – "MIMO radar theory and experimental results" – Signals, Systems and Computers, 2004. Conference Record of the 38th Asilomar Conference on Volume 1, 7-10 Nov. 2004 Page(s):300 - 304 Vol.1.