Interference Control in the Coexistence of Radar and Communication Systems

MOHAMMED HIRZALLAH AND TAMAL BOSE
ECE DEPARTMENT, THE UNIVERSITY OF ARIZONA

2015 – 03 – 27, WINCOMM 2015

Motivation

- Spectrum Sharing is proposed as one of the solutions to the spectrum scarcity. However, there are many associated challenges.
- Among these challenges is the flexibility of controlling the interference in a time varying wireless channel that is inherent with multipath fading and shadowing effects.
- In these slides we are addressing this challenge

Problem Description

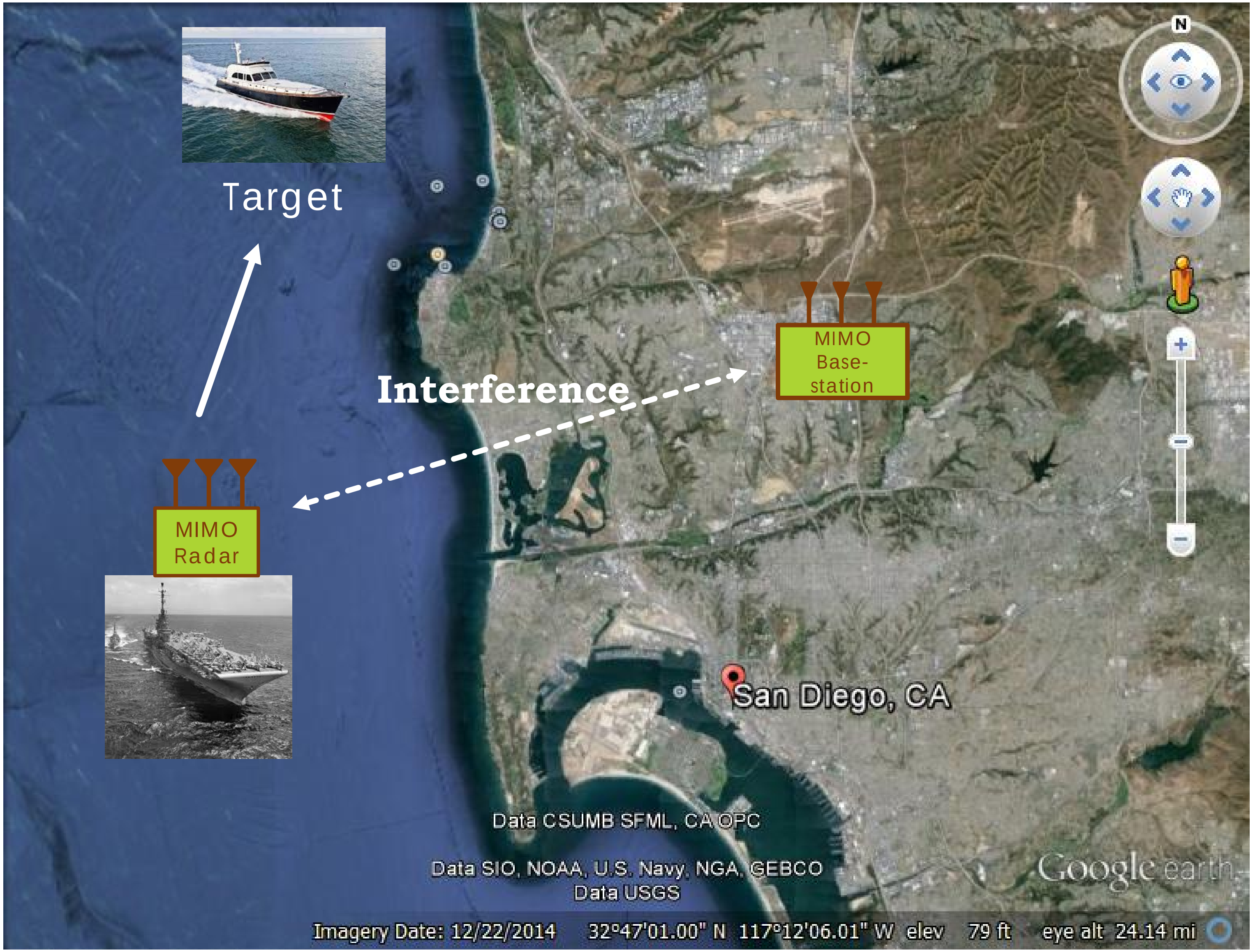
- Controlling/Estimating the interference based on path loss model alone is not always accurate due to time-varying nature of the wireless channel.
- Some models do include fading and shadowing effects. We can rely on these models to estimate the received interference. However, these models are not real-time oriented.
- We are looking for an interference control tool that is:
  - Accurate / flexible
  - Takes fading and shadowing effects into account.
  - Suitable for real-time implementations
- We propose a solution that is based on "Subspace Methods"

Agenda

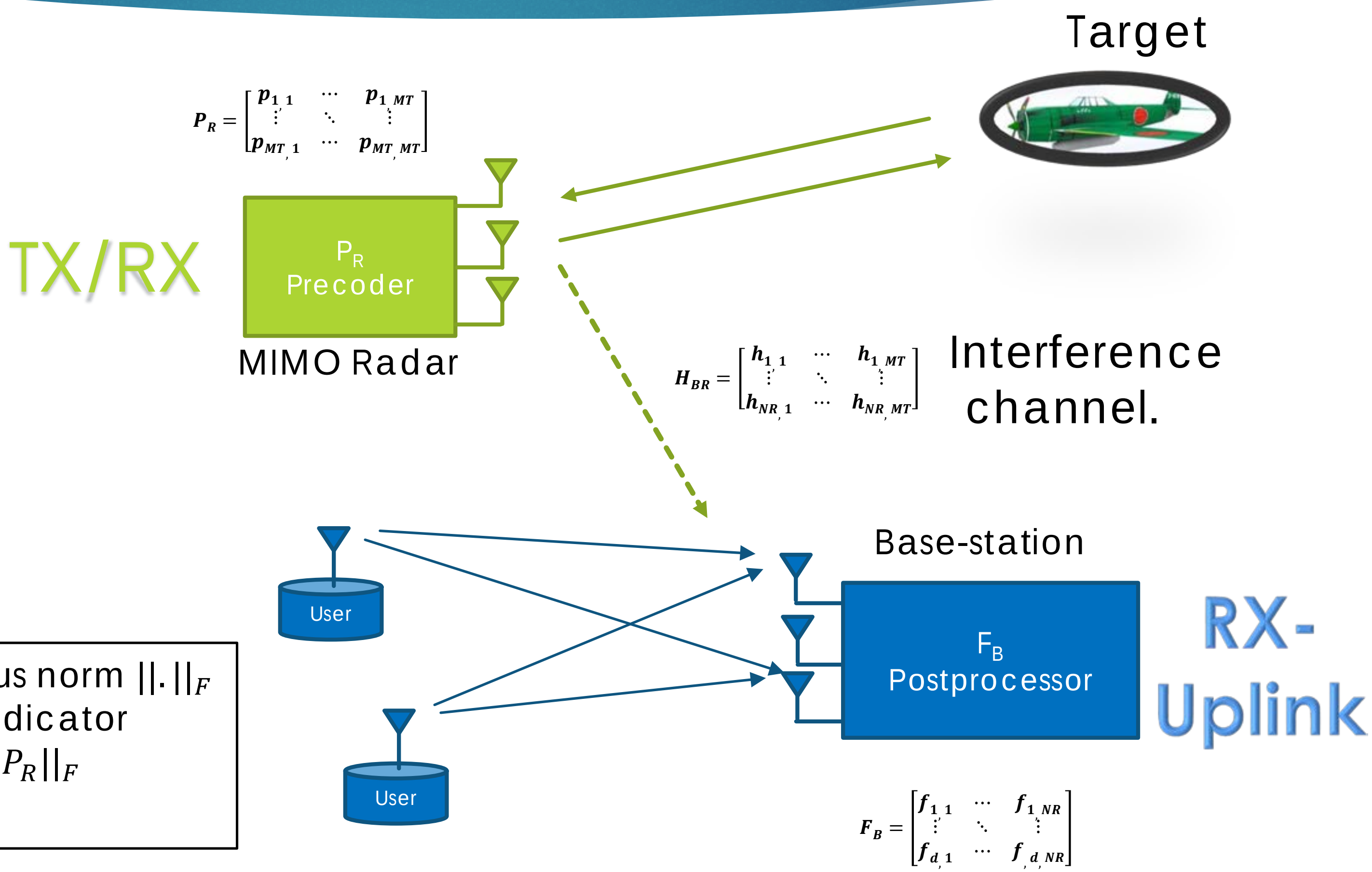
- System Model
- Proposed Solution
  - Subspace Based Methods - Polynomial Method
- Results and Discussions
- Appendices

System Model

Example, spectrum sharing at the 3.5 GHz spectrum band in San Diego (Expected in the Future)



1. System Model



We use the Frobenious norm $||.||_F$ as an interference indicator

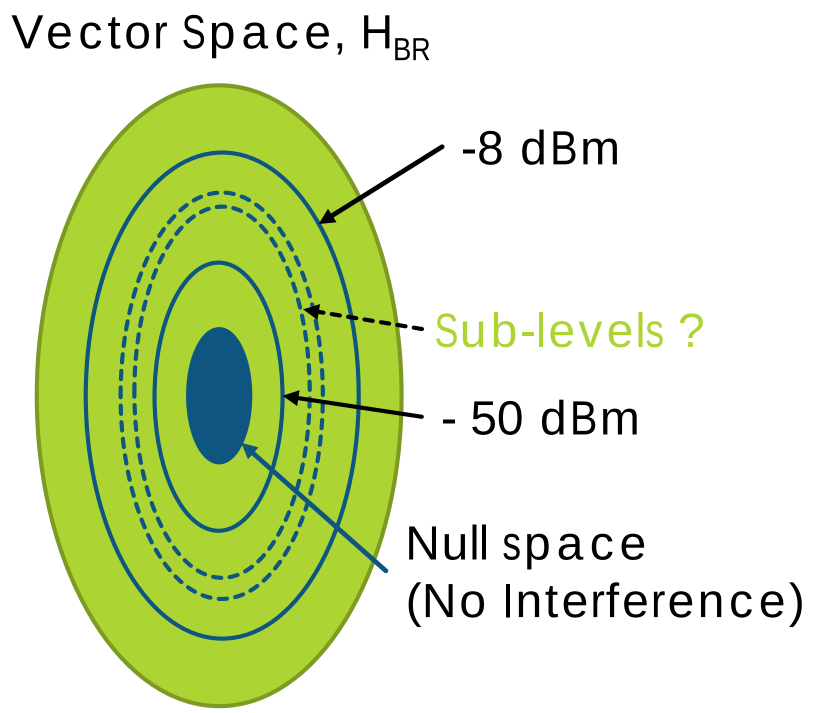
$$D_{th} = ||F_B H_{BR} P_R||_F$$

3. Proposed Solution

Polynomial-Based Subspace Method

1. Literature Review - Subspace Based Solutions

- Previous work handled interference according to a subspace expansion perspective [1][2].
- These methods are limited in terms of number of possible interference levels they could approach. In other words, they do not have enough freedom to increase/decrease interference up to any level.



[1] S. Sodagari, A. Khawar, T. C. Clancy, and R. McGwier, “A projection based approach for radar and telecommunication systems coexistence,” in *2012 IEEE Global Communications Conference (GLOBECOM)*, 2012, pp. 5010–5014.
[2] A. Babaei, W. H. Tranter, and T. Bose, “A nullspace-based precoder with subspace expansion for radar/communications coexistence,” in *2013 IEEE Global Communications Conference (GLOBECOM)*, 2013, pp. 3487–3492.

2. Subspace Method – Polynomial Method

1

$$H = F_B\, H_{BR} = \begin{bmatrix} h_{1,1} & \cdots & h_{1,NR} \\ \vdots & \ddots & \vdots \\ h_{NR,1} & \cdots & h_{NR,NR} \end{bmatrix}$$

2

$$H_{poly} = \alpha_1\, H^{\beta_1} + \alpha_2\, H^{\beta_2} + \ \ldots + \alpha_n\, H^{\beta_n}$$

Powers are taken as Hadamard product

$$H_{poly} = \begin{bmatrix} \bar{h}_{11} & \cdots & \bar{h}_{1,NR} \\ \vdots & \ddots & \vdots \\ \bar{h}_{NR,1} & \cdots & \bar{h}_{NR,NR} \end{bmatrix}$$

$$\bar{h}_{1,1} = \alpha_1\, h^{\beta_1} + \alpha_2\, h^{\beta_2} + \ \ldots + \alpha_n\, h^{\beta_n}$$

Polynomial method cont'd

3

$$H_{poly} = U\Sigma V^H =$$

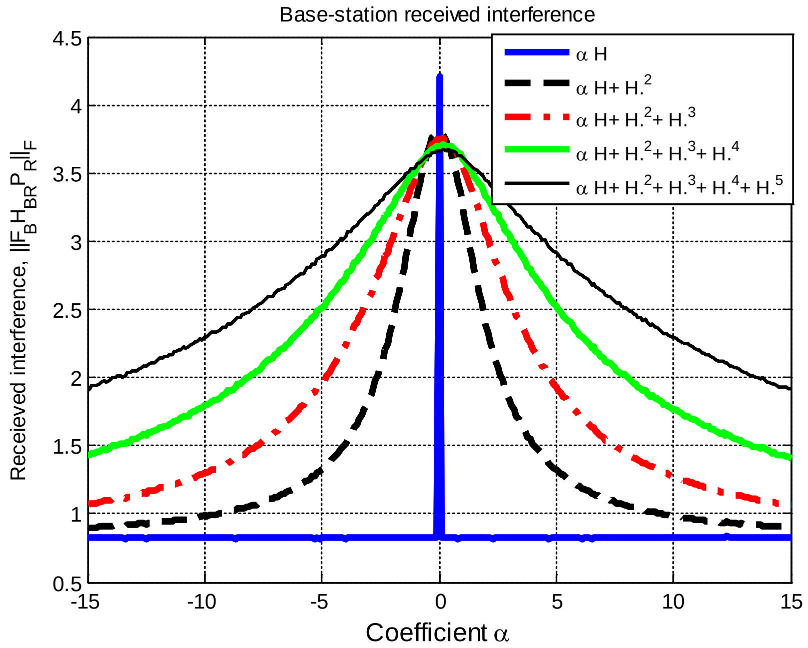
$$\begin{bmatrix} u_{11} & \cdots & u_{1,NR} \\ \vdots & \ddots & \vdots \\ u_{NR,1} & \cdots & u_{NR,NR} \end{bmatrix} \begin{bmatrix} \sigma_1 & \cdots & 0 \\ \vdots & \sigma_r & \vdots \\ 0 & \cdots & 0 \end{bmatrix} \begin{bmatrix} v_{11} & \cdots & v_{1,MT} \\ \vdots & \ddots & \vdots \\ v_{MT,1} & \cdots & v_{MT,MT} \end{bmatrix}^H$$

4 $\tilde{V}$

5 $P_R = \tilde{V}\ (\tilde{V}^H\tilde{V})^{-1}\tilde{V}^H$

The remaining question is how to select the proper polynomial's parameters, namely, coefficients $\bar{\alpha} = \{\alpha_1, \cdots, \alpha_n\}$ and powers $\bar{\beta} = \{\beta_1, \cdots, \beta_n\}$. We answer this question on the next slides.

Selection of a Proper Polynomial Format



The second order polynomial spans good interference range and requires lower computational complexity compared to other higher order polynomials.

Summary - Algorithm

- Inputs: H_{BR}, F_B, D_{th}
- Start:
  - 1. Run Genetic Algorithm (GA) to find (α) in $\mathrm{H}_{\mathrm{poly}} = (H_{eff}).^2 + \alpha\, H_{eff}$ such that $D_{th} = ||F_B H_{BR} P_R||_F$
  - 2. Project P_{R} into the null space of $\mathrm{H}_{\mathrm{poly}}$
- Output: P_{R}
- Loop to Inputs

4. Results and Discussion

1. Assumptions and Simulation parameters

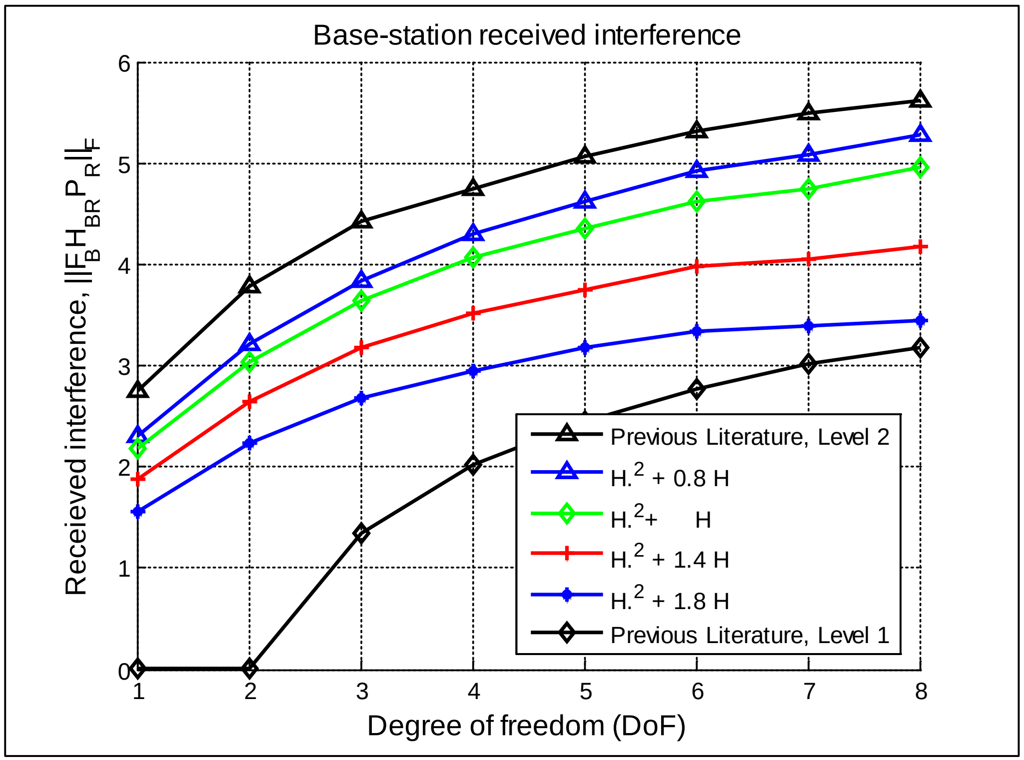
Assumptions

- We assume the channel between radar and communication system is a flat-block fading channel.
- We assume radar has a perfect knowledge about input parameters, i.e, $\{H_{BR}, F_B,\ D\}$
- We control the interference generated by radar and confine it to a tolerable level D.
- We are interested in examining the tool ability to confine the interference to D level and examine the impacts over radar performance.

Simulation Parameters

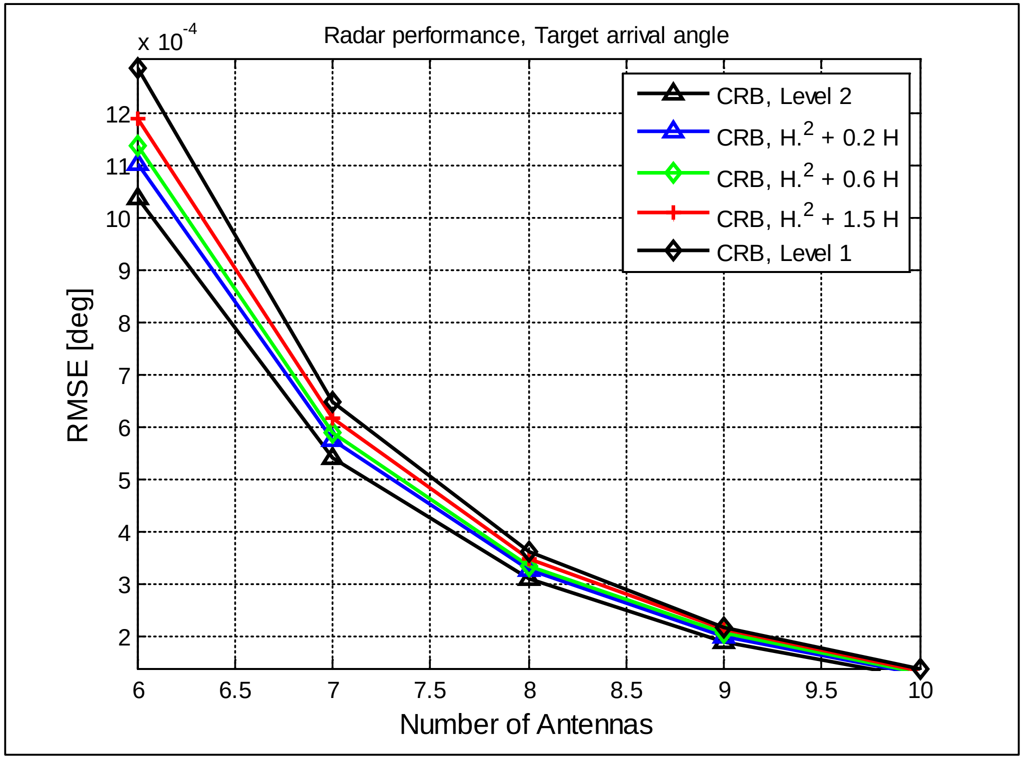
Parameter name	Value
Radar – Antennas	8x8
Radar – Target Range	10 Km
Radar – Target Direction of Arrival (DOA)	30 degree
Radar – SNR	20 dB
Radar – Antenna spacing	$3\lambda/4$
Operating frequency	3.5 GHz
Base-station – Antennas	8x8
Base-station – number of users	1,2,3,4,5,6,7,8

Received Interference



Changing the polynomial coefficient α in $(H_{eff}).^2 + \alpha\, H_{eff}$ controls the received interference by the base-station.

Radar Performance



Changing the polynomial coefficient α in $(H_{eff}).^2 + \alpha\, H_{eff}$ controls radar performance (estimating targets azimuth angle)

Conclusion

- We have proposed an adjustment to subspace methods to overcome their limitations. We propose the Polynomial method.
- The new proposed tool constrains the interference in a flexible manner and is helpful for spectrum sharing and coexistence applications
- Polynomial format can be selected based on the desired system behavior. Coefficient α can be obtained using a proper searching method.
- The proposed can be used as a general subspace expansion method.

Questions ?

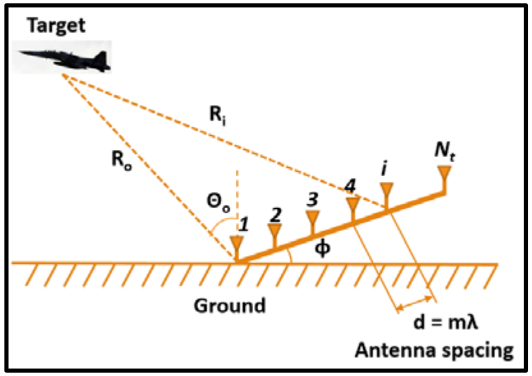
Appendix 1 – Radar Cramer Rao Bound (CRB)

$$CRB(\theta) = \frac{1}{2SNR}(N_t \dot{\mathbf{a}}_{\mathbf{t}}{}^*(\theta)\mathbf{R_s}{}^T \dot{\mathbf{a}}_{\mathbf{t}}(\theta)$$
$$+\mathbf{a_t}{}^*(\theta)R_s^T\mathbf{a_t}(\theta)||\dot{\mathbf{a}}_{\mathbf{r}}(\theta)||^2 - \frac{N_t|\mathbf{a_t}{}^*(\theta)R_s^T\dot{\mathbf{a}}_{\mathbf{t}}(\theta)|^2}{\mathbf{a_t}{}^*(\theta)R_s^T\mathbf{a_t}(\theta)})^{-1} \quad (1)$$

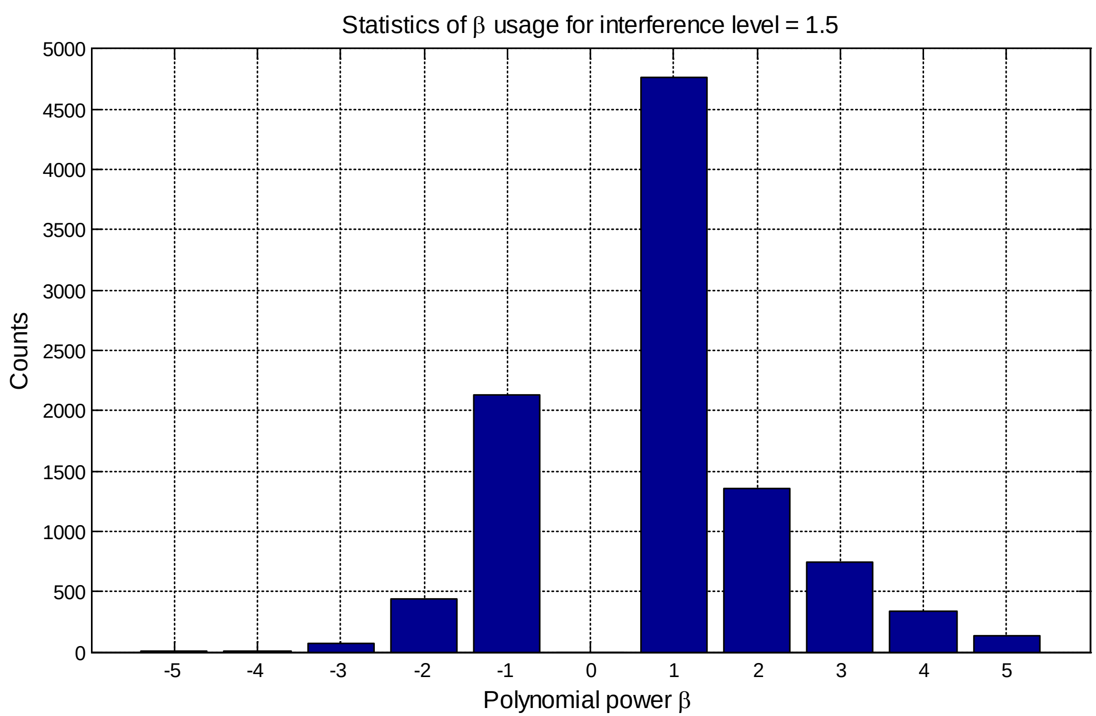
where, where SNR is the radar signal to noise ratio, $\mathbf{a_t}(\theta) = [a_{1,t}(\theta)a_{2,t}(\theta)\cdots a_{N_t,t}(\theta)]^T$, $\mathbf{a_r}(\theta) = [a_{t,1}(\theta)a_{t,2}(\theta)\cdots a_{t,N_r}(\theta)]^T$, $\dot{\mathbf{a}}_{\mathbf{t}}(\theta)$ is simply the derivative of $\dot{\mathbf{a}}_{\mathbf{t}}$ with respect to the angle θ.

$$R_s = \frac{1}{K}\cdot\sum_{n=1}^{k}\bar{s}[n]\bar{s}^*[n] = P_R P_R^* \quad (2)$$

[1] I. Bekkerman and J. Tabrikian, "Target Detection and Localization Using MIMO Radars and Sonars," IEEE Trans. Signal Process., vol. 54, no. 10, pp. 3873-3883, Oct. 2006.



Appendix 2 – Polynomial Format statistics



Polynomial order β	Percent usage percentage by GA
1	66 %
2	19 %
3	9 %
4	4%
5	2%

$$H_{poly} = \alpha_1 \, H_{\cdot}^{\beta_1} + \alpha_2 \, H_{\cdot}^{\beta_2}$$