A METHOD FOR OPTIMAL SCHEDULING OF ACTIVE ELECTRONICALLY SCANNED ARRAY (AESA) ANTENNAS

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ABSTRACT

Today, it is very common to install and use communications, Electronic Warfare (EW) and radar payloads on a single platform. This causes location and interoperability problems even on large platforms like ships where there exist no tight weight and space limitations. However, this may be a serious problem, that shall be handled with highest priority, on small platforms like UAVs and fighters. Joint usage of the antenna and RF layers on board the platform by communication, EW and radar payloads is a smart solution to the location problem and thanks to evolving technologies like active phased-array antennas, MMIC (Monolithic Microwave Integrated Circuit) and MEMS (Micro Electrical-Mechanical Systems) now it is possible to common up the RF components on small platforms and reduce the weight, space and power requirements. In this work, we propose a method for optimal scheduling of the AESA antennas which can be used for radar and EW system commonly.

Keywords: AESA, Resource Management, Multi-functional Antennas

1. INTRODUCTION

Active phased-array antennas, with their high scan rates, provide effective detection and tracking opportunities to radars in multi-target environments. Experience gained on multi-function radar studies has opened the road to using a single RF layer and multi-function antenna for all communication, EW and radar payloads [2]. Using a single antenna for more than one function makes it possible to reduce the radar cross section, weight and volume of the platform. Besides their advantages, multi-functional antennas have a main disadvantage which is the problem of optimizing the scan time among the functions supported. This paper, suggests a solution to antenna resource management problem for multi-functional Active Electronically Scan Array (AESA) antennas.

As antenna beam can be switched very fast and multiple beams can be generated at a time with AESA antennas, multiple tasks like search and tracking for radar and emission detection and jamming for EW systems can be performed using a single antenna. Meaning that, tasks of various systems on the platform can be performed by a single AESA antenna by switching the beam on time and angle.

Antenna resource management problem can be evaluated as a multi-dimensional parameter selection problem to determine the parameters that control the task revisit internal time and task dwell duration [1]. Dynamic scenario and sequential measurements obtained from the environment are most critical points of this problem. These measurements shall be performed with low computational load for real time operations [1].

Various research studies exist for scheduling of radar functions of multi-functional radars and for optimizing scan regime of EW receivers for the target list. However, studies can rarely be found for optimizing antenna beam allocation among the functions when both radar and EW systems use the same antenna. This paper handles the case where both radar and EW systems use the same AESA antenna infrastructure. A method to determine the optimal dwell time and revisit time interval pair for each function of radar and EW payloads is proposed.

2. RESOURCE MANAGEMENT PROBLEM DEFINITION

Resource management problem handles a set of K independent tasks {T_1, T_2, …, T_K}, which share a time budget. Operational parameters are determined for each task by optimization. Valid parameter selection for each measurement is very critical [1].

Measurements for each task at time t is denoted by v_{tk}. Environmental parameters, like bearing and uncontrolled range, for each task are denoted by e_{tk}. As these environmental parameters are unknown, they have to be estimated using the measurements.

Selected operational parameters for each task has impact on the resource load of the task. Resource load of task T_k at time t is denoted by r_{tk} (Equation(*1*). Resource load is defined by a resource function which maps environmental parameters to operational parameters in resource space [1].

$$r_{tk} = g_k(v_{tk}, e_{tk}) \quad (1)$$

The infrastructure which manages all tasks has limited time budget. When usable total resource is denoted by $\hat{r}_t$, resource function can be expressed with Equation (*2*.

$$g(v_t) = \left(\sum_{k=1}^{K} g_k(v_{tk}, e_{tk}\right) - \hat{r}_t \quad (2)$$

Resource function has to satisfy the constraint given at Equation (*3*.

$$g(v_t) \leq 0 \quad (3)$$

Operational parameters selected for the task at every measurement time t affect the task quality. Expected task quality is given by Equation (*4*.

$$q_{tk} = q_k(v_{tk}, e_{tk}) \quad (4)$$

Utility function is defined as mapping from task quality space to task utility space (Equation *(* *5*). At any measurement time, utility of any task is denoted by u_{tk} and utility space is denoted by u_k.

$$u_{tk} = u_k(q_k(v_{tk}, e_{tk})) \quad (5)$$

Total utility at any measurement time is the sum of all task utilities (Equation (*6*).

$$u(v_k) = \sum_{k=1}^{K} u_k(q_k(v_{tk}, e_{tk})) \quad (6)$$

Each task utility represents the performance associated with own task quality and hence total utility represents the overall performance of the tasks managed by the system. Therefore, resource management problem can be formulated as an optimization problem limited to measurement time t:

$$maximise: u(v_t) = \sum_{k=1}^{K} u_k\big(q_k(v_{tk}, e_{tk})\big)$$

$$subject\ to: g(v_t) \leq 0$$

$$where: g(v_t) = \left(\sum_{k=1}^{K} g_k(v_{tk}, e_{tk})\right) - \hat{r}_t$$

3. TARGET PLATFORM MODEL

3.1. Platform Acceleration Model

In this study platform motion is modeled using Singer Acceleration Model. In this model, acceleration of the platform is modeled by a Markov process [5]. The state space representation of process is given by:

$$x_{k+1} = \begin{bmatrix} 1 & T & (\theta T - 1 + e^{-\theta T})/\theta^2 \\ 0 & 1 & (1 - e^{-\theta T})/\theta \\ 0 & 0 & e^{-\theta T} \end{bmatrix} x_k + w_k \quad (7)$$

$$Var(w_k) = \Sigma.2\Theta$$

Θ and Σ are design parameters and the performance of Singer model depends on the accuracy in determining them. The Θ is defined as the reciprocal of the maneuver time constant and depends on how long the maneuver lasts. For example, for an aircraft's lazy turn it can be 60 seconds and for an evasive maneuver 10-20 seconds. Σ is the instantaneous variance of acceleration treated as a random variable [5].

In this paper, acceleration of all airborne platforms is modeled using Singer Model. This paper handles the cases where radar platforms, which are targets of EW system, are both assumed as stationary platforms on the ground and airborne.

3.2. Target Platform Radar Cross Section (RCS) Model and Target Radar Output Power

RCS of radar targets is modeled using Swerling I Model. In Swerling I Model, RCS is assumed as a Rayleigh distributed random variable which is independent on sequential scans. Cumulative distribution function of Rayleigh distribution is given in Equation (8.

$$F(r) = 1 - \exp\left(-\frac{r^2}{2\sigma^2}\right) \quad (8)$$

In this study, Rayleigh distributed random numbers are generated by replacing uniform distributed random numbers in place of "u" in Equation (9.

$$r = [-2\sigma^2 \ln(1-u)]^{1/2} \quad (9)$$

Received power of the radar platform, which is the target of EW system, is calculated using free space loss model.

4. RESOURCE MANAGEMENT MODEL

In this paper, a variation of Van Keuk and Blackman (VBK) Model proposed at [1] is used to optimize operational parameters of EW and radar payloads. VBK Model assumes that multiple targets tracked by AESA have enough distance separation [4]. Radar targets are modeled as point targets on VBK model. Antenna beam is directed to estimated position of the target on the angle space when the track is updated. Beam positioning power loss is observed if there exists an offset between the estimated and actual positions of the target. In VBK Model, this power loss is modeled by a Gaussian loss function matched with antenna beam width.

It is assumed that additive Gaussian noise exists on the angular position measurements of the targets. Standard deviation of the Gaussian noise is given in Equation (*10*.

$$\sigma = \frac{2.\theta_B}{k_m\sqrt{2.SNR}} \tag{10}$$

In Equation (*10*, k_m denotes the slope of monopulse error curve and this slope is calculated as $\sqrt{2}.SNR$ in VKB Model and θ_B is the 3 dB beam width of the antenna.

VKB proposes a strategy which schedules track updates when the angular estimation error is equal to a fraction of half beam width. Fraction of half beam width is called track sharpness and is denoted with v_0. The aim of this strategy is to minimize the track loading by using short and long revisit interval times. While short revisit intervals increase track loading by higher track update frequency, long revisit intervals increase track loading because of increased beam positioning error due to less measurement accuracy and detection probability. Hence optimization is required to calculate the most suitable revisit interval.

Track revisit time is calculated using Equation (*11*, where R denotes target range, and Θ and Σ denote Singer model parameters.

$$t_r = 0.4\left(\frac{R\sigma\sqrt{\Theta}}{\Sigma}\right)^{0.4}\frac{U^{2.4}}{1+\frac{1}{2}U^2} \tag{11}$$

Variance reduction ratio, is calculated as the ratio of measurement error to track estimation error and given in Equation (*12*.

$$U = \frac{\theta_B v_0}{\sigma} \tag{12}$$

Standard deviation of measurement noise is denoted with σ and calculated using Equation (*10*. Number of looks at every track update is denoted with n_l and calculated using Equation (*13*.

$$n_l = \frac{1}{P_d}(1+(\gamma v_0^2)^2)^{1/2} \tag{13}$$

$$\gamma \approx 1 + 14\left(\left|lnP_f\right|/SN_0\right)^{1/2} \tag{14}$$

P_f in Equation (*14* denotes the used false alarm rate. Expected SNR is calculated approximately by using Equation (*15*.

$$SNR = \frac{SN_0 - lnP_f}{1+2v_0^2} \tag{15}$$

SN_0 denotes the SNR level when there is no beam positioning error.

$$SN_0 = \left(\frac{R_0}{R_t}\right)^4\left(\frac{\rho}{\rho^n}\right)\left(\frac{\tau_c}{\tau_c^n}\right)cos^3\theta_t \tag{16}$$

Where,

R_t: Target range.

ρ: Target radar cross section.

τ_c^n : Nominal coherent dwell duration.

ρ^n: Nominal radar cross section.

θ_t: off-boresight scan angle.

τ_c: Dwell duration

Resource function is defined by Equation (*17*, where τ_c denotes dwell duration and t_r denotes revisit interval time.

$$r = \frac{n_l \tau_c}{t_r} \quad (17)$$

Track sharpness v_0 is calculated by finding roots of Equation (*18*.

$$1 + \left(\frac{\beta}{2} + 2\right) v_0^2 - \alpha \beta v_0^{2.4} = 0 \quad (18)$$

$$\beta = SN_0 - lnP_f$$

$$\alpha = \frac{0.4}{t_r} \left(\frac{R_t \theta_B \sqrt{\Theta}}{\Sigma}\right)^{0.4}$$

The utility function describes the satisfaction that is associated with the achieved track accuracy.

$$u = 1 - exp\left(\frac{-\eta}{v_0 \theta_B}\right) \quad (19)$$

η denotes sensitivity to the track accuracy and $v_0 \theta_B$ denotes angular estimation error. Relation between utility and angular estimation error for various sensitivity values is given in Figure 1.

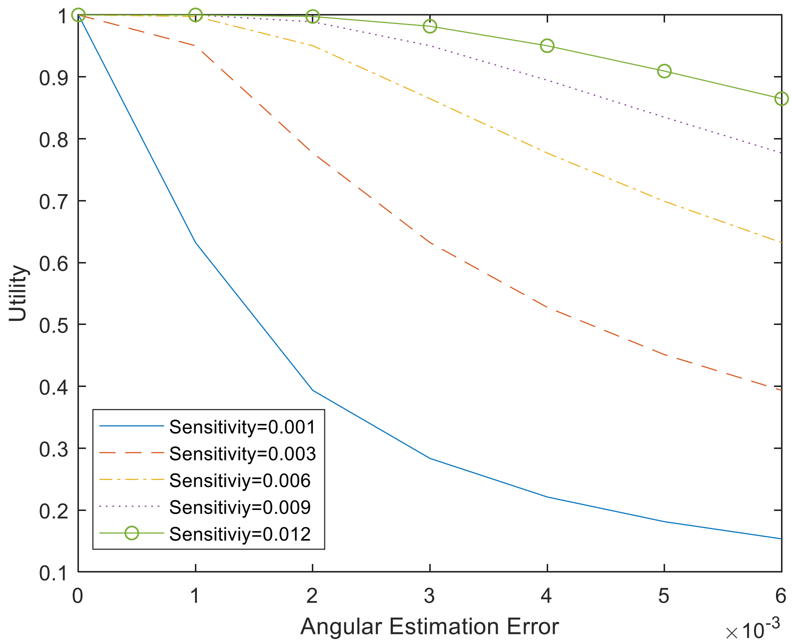

Figure 1 Utility versus angular estimation error for various sensitivity values.

5. SIMULATION RESULTS

Simulations are performed to see the impact of following parameters on the utility of EW task when EW system's target radar is surface stationary and airborne.

- EW system's target radar output power
- Sensitivity

- Number of radar tasks (N)

Simulation results are given in Tables 1 to 4.

Table 1 Utility of EW task when target radar output power is low and target radar platform is airborne.

	sensitivity=0.001	sensitivity =0.003	sensitivity =0.006
N=2	0.99901519541	0.99969466760	0.99998453306
N=6	0.99901519541	0.99969466760	0.99998453306
N=10	0.98837164806	0.99969466760	0.99998453306
N=15	0.98837164806	0.99969466760	0.99998453306
N=20	0.98837164806	0.99969466760	0.99998453306
N=25	0.98837164806	0.99969466760	0.99998453306
N=32	0.98837164806	0.99969466760	0.99998453306

Table 1 shows that number of radar tasks is the main factor that affects utility of EW task when received power is low and sensitivity is low.

To analyze the impact of the target radar output power, simulation is repeated for medium and high output power values and results are given in Table 2 and Table 3, respectively. When the target radar output power is medium or high, utility is not affected by the number of radar tasks. A difference is observed when the sensitivity is 0.003 and number of radar tasks is 32 but it is negligible.

Table 2 Utility of EW task when target radar output power is medium and target radar platform is airborne.

	sensitivity=0.001	sensitivity =0.003	sensitivity =0.006
N=2	0.99578333599	0.99997883745	0.99999256983
N=6	0.99578333599	0.99997883745	0.99999256983
N=10	0.99578333599	0.99997883745	0.99999256983
N=15	0.99578333599	0.99997883745	0.99999256983
N=20	0.99578333599	0.99997883745	0.99999256983
N=25	0.99578333599	0.99997883745	0.99999256983
N=32	0.99578333599	0.99961136509	0.99999256983

Table 3 Utility of EW task when target radar output power is high and target radar platform is airborne.

	sensitivity=0.001	sensitivity =0.003	sensitivity =0.006
N=2	0.99779688215	0.99999344355	0.99999713764
N=6	0.99779688215	0.99999344355	0.99999713764
N=10	0.99779688215	0.99999344355	0.99999713764
N=15	0.99779688215	0.99999344355	0.99999713764
N=20	0.99779688215	0.99981761997	0.99999713764
N=25	0.99779688215	0.99981761997	0.99999713764
N=32	0.99779688215	0.99981761997	0.99999713764

Simulation is repeated for the stationary surface target radar to see the impact of the target radar environment on utility. Allocated revisit time for the stationary target radar is larger compared to airborne target radar, which causes decrease in utility. Number of radar tasks has more impact on utility and affects the utility even for medium and high sensitivity values.

Table 4 Utility of EW task when target radar output power is medium and target radar platform is surface stationary.

	sensitivity=0.001	sensitivity =0.003	sensitivity =0.006	sensitivity =0.009	sensitivity =0.012
N=2	0.66616685048	0.94134631246	0.98096918595	0.99259031501	0.99542914321
N=6	0.66616685048	0.94134631246	0.98096918595	0.99259031501	0.99542914321
N=10	0.63199650171	0.94134631246	0.98096918595	0.99259031501	0.99542914321
N=15	0.52605503343	0.94134631246	0.98096918595	0.99259031501	0.99542914321
N=20	0.52605503343	0.91473866327	0.98096918595	0.99259031501	0.99542914321
N=25	0.52605503343	0.86204778347	0.98096918595	0.99259031501	0.99542914321
N=32	0.38264025015	0.86204778347	0.98096918595	0.99259031501	0.99542914321

Utility of EW task and radar task is compared in Figure 2 and Figure 3 for stationary target radar and airborne target radar. Comparison shows that utility of EW task is higher than the radar tasks when the target radar is airborne, whereas utility of EW task is slightly smaller than radar tasks when the target radar is stationary.

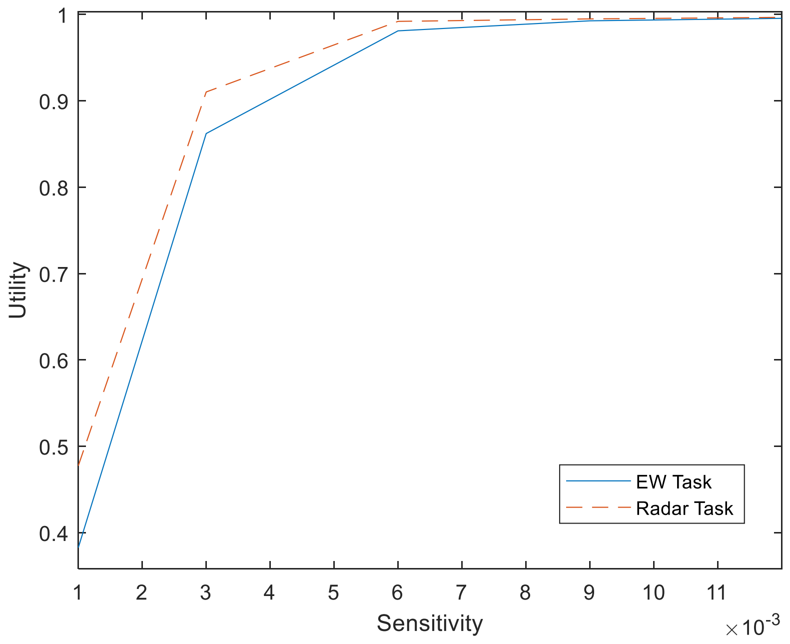

Figure 2 EW task and radar task utilities when target radar platform is stationary.

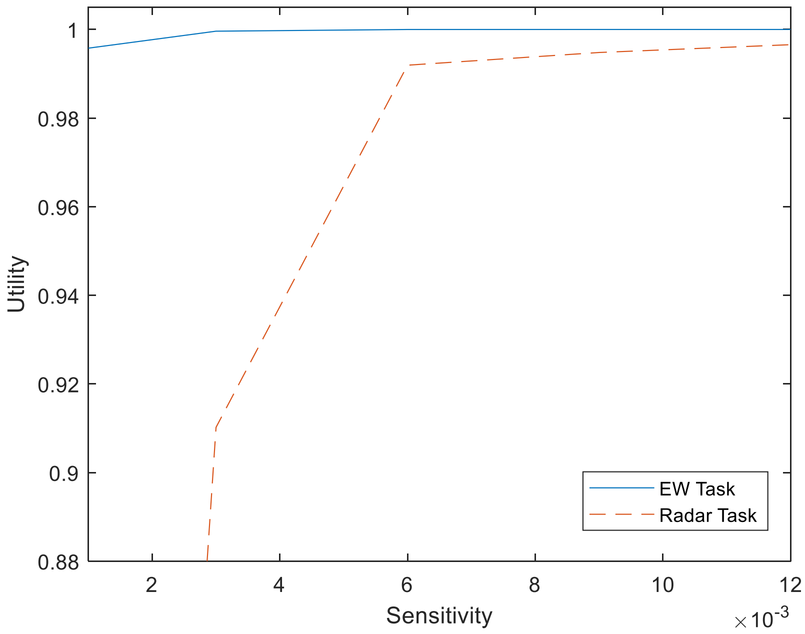

Figure 3 EW task and radar task utilities when target radar platform is airborne.

6. CONCLUSION

This paper proposes a method, which is based on a variant of VBK Model given in [1], for resource management when the resources are utilized by both EW task and radar tasks. This study introduced EW task with target radar environment parameters to model of [1]. Analysis has been made for various cases and consistent results are achieved showing that EW task and radar tasks can utilize the same resources. Analysis has been made by assuming that target radar's antenna is stationary and beam is always directed towards AESA. For the search radar case this is not a valid assumption and further research can be performed to handle scanning target radar antennas.

7. REFERENCES

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