MITIGATION FACTORS FOR MULTI-DOMAIN RESILIENT NETWORKED DISTRIBUTED TESSELLATION COMMUNICATIONS

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Introduction

Radio Frequency (RF) Communications

Resilient Networked Distributed Tessellation Communications (RNDTC)

Signal processing functions of RNDTC enable the various polygons to self-form into an array and enable beamforming, among other techniques, thereby enhancing the desired signals and somewhat obviating intentional/unintentional interference.

RNDTC are comprised of spatially distributed low Size, Weight, Power, and Cost (SWaP-C) transceiver polygons.

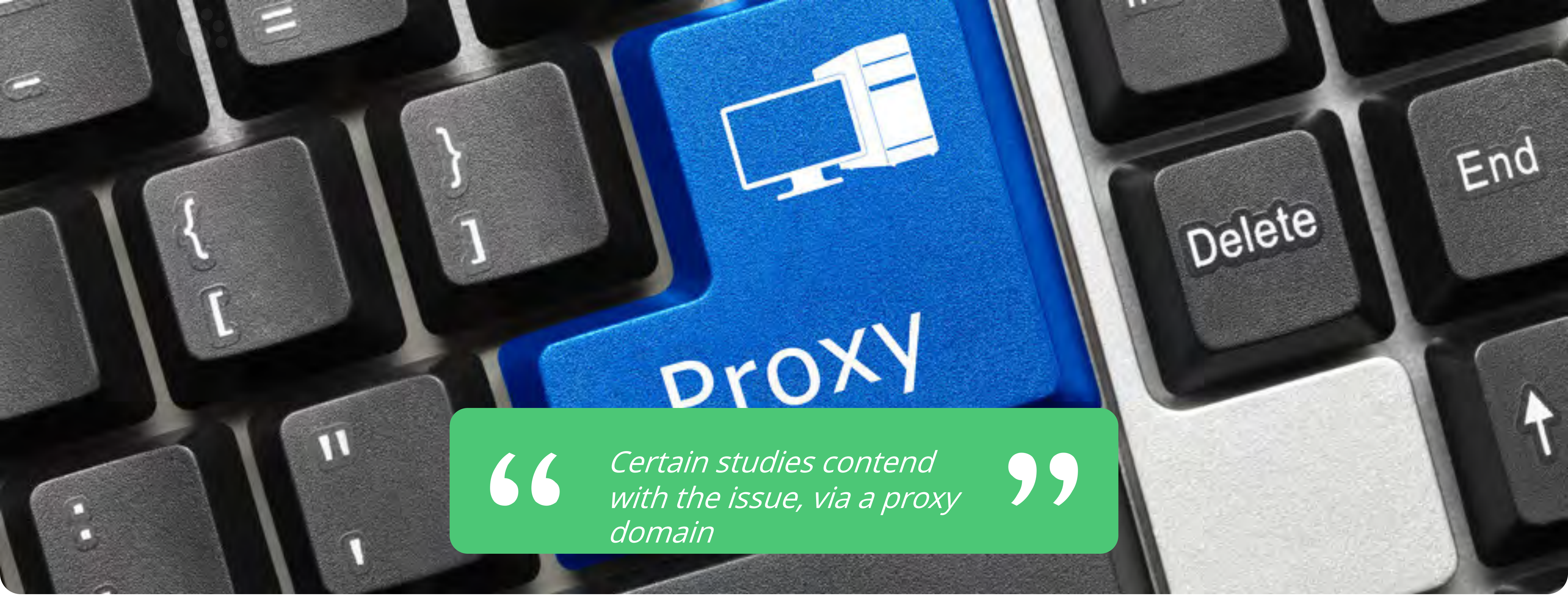
INTRODUCTION

The Purpose of Research

The algorithmic approaches to date have varied pros and cons (e.g., the attainment of reduced sidelobes at the expense of the mainlobe, wherein interference suppression is achieved at the cost of the resolution of the signals). despite the advantages of adaptive weighting techniques, the computational complexity is extremely high, and the ensuing complexity reduction processes are subject to adversarial exploitation.

This paper proposes mitigation factors by way of Artificial Intelligence (AI)-centric Genetic Algorithm (GA) approaches amidst the analysis, transformation, and synthesis amalgam

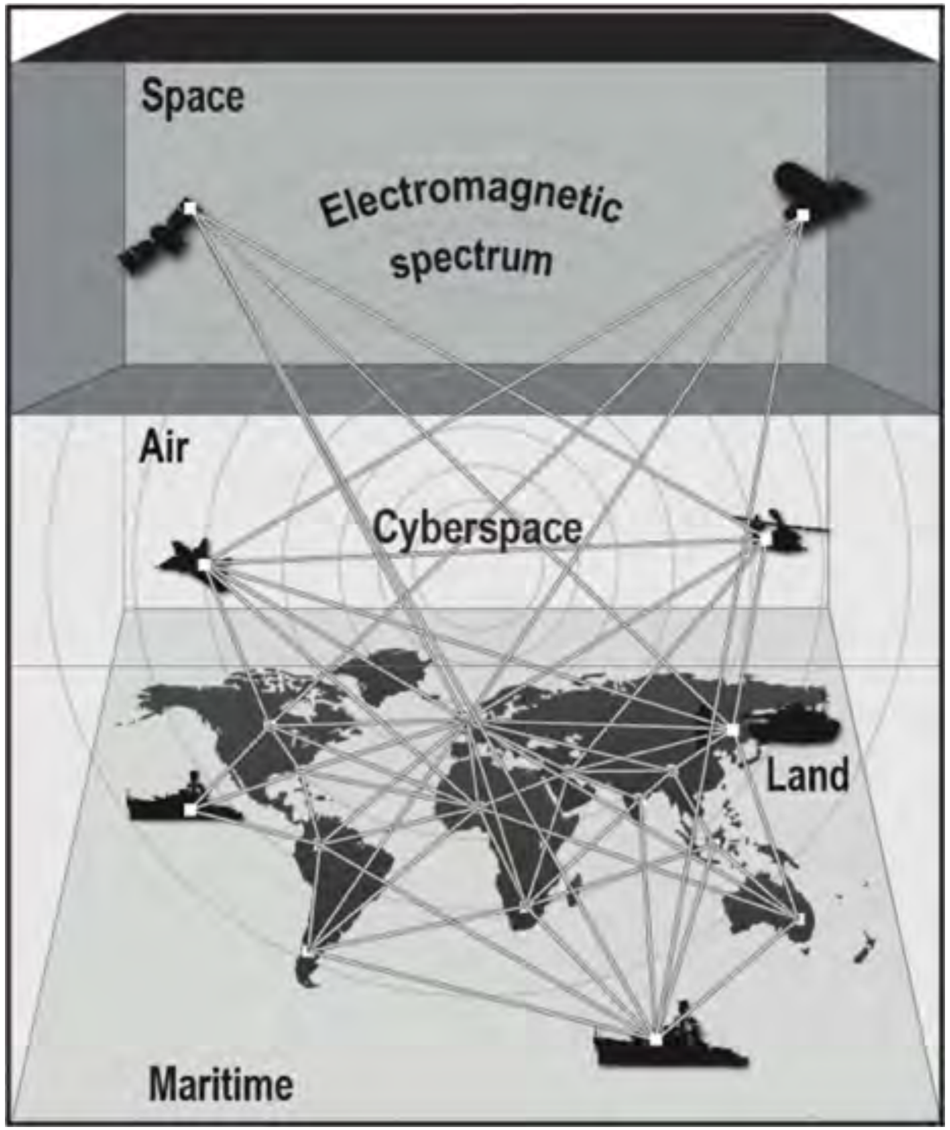
Related Work in the Literature, the Operating Environment, and the State of the Challenge



> *Certain studies contend with the issue, via a proxy domain*

Related Work in the Literature

The probabilistic availability of URC in such a proxy network are generally analyzed “cell-wise and/or system-wise,” and Poisson point process and Voronoi tessellation tend to be utilized in the modeling of the spatial characteristics of cell deployment in both homogeneous and heterogeneous networks.



Potential Non-permissive Domains

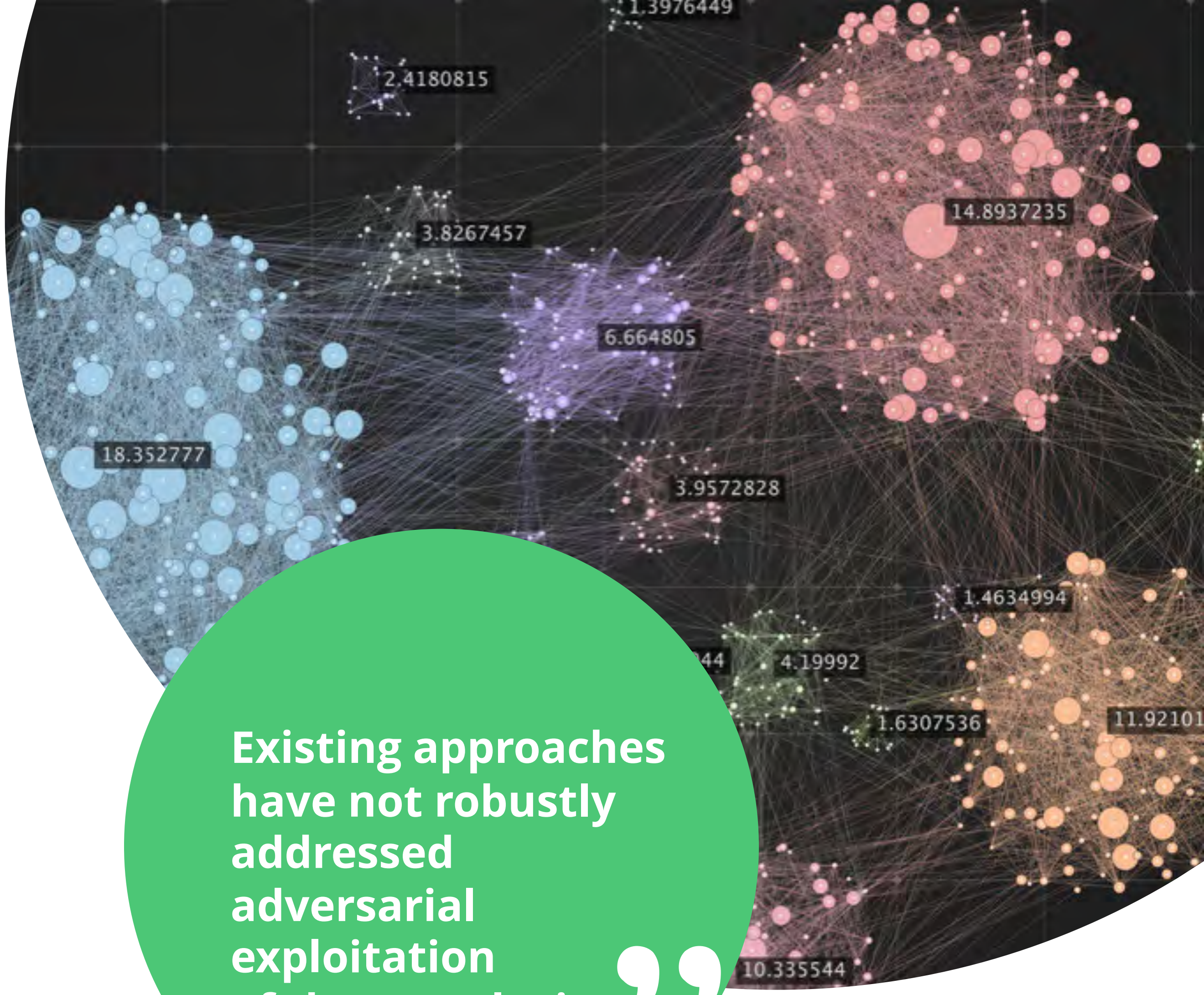
The Operating Environment

From a Cyber Warfare Field Manual:

“Cyber Electromagnetic Activities” encompasses not only the conventional activities involving electronic warfare and spectrum management operations, but also elements of cyberspace operations.

The State of the Challenge

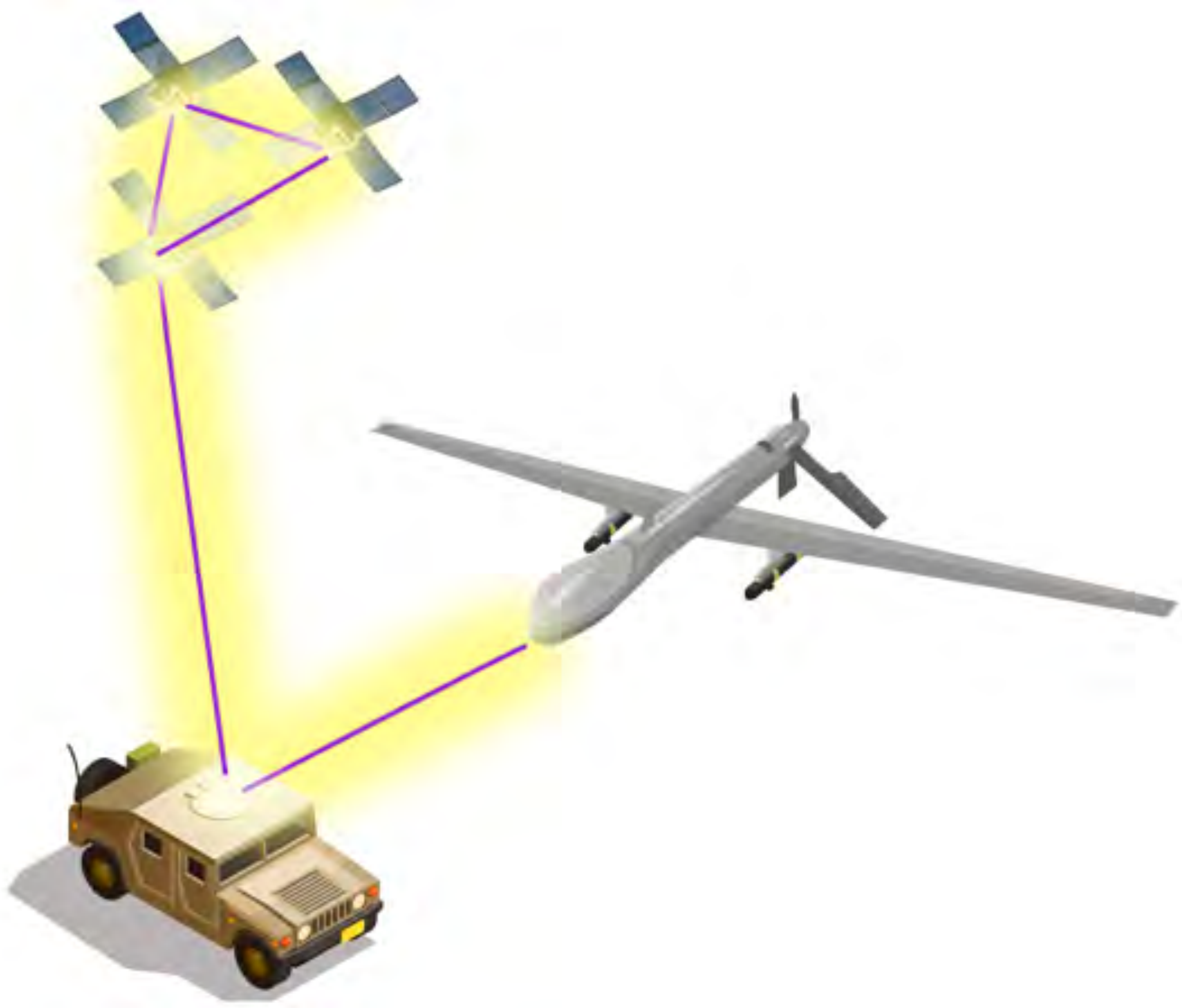
The nature of the challenge centers upon a core need to **reduce computational complexity** when considering the myriad of system parameters interplaying into the achievable link availability.



Existing approaches have not robustly addressed adversarial exploitation of the complexity reduction process

Transceiver Polygons

The resolution of the challenge for transceiver polygon applications has far-reaching implications for a variety of sectors (e.g., defense, intelligent transportation systems, etc).



The Signal Processing Intent of Resilient Networked Distributed Tessellation Communications (RNDTC) and A True Adaptive Beamforming Approach

SIGNAL PROCESSING TASKS

01

An adaptive beamforming algorithm that will enhance the beamforming and endeavor to mitigate against interference morphological adjustments.

02

Advance a hybridized Adaptive Weight Vector (AWV) algorithm conjoined with a decomposition-based evolutionary algorithm (a.k.a. Genetic Algorithm or GA), which are both supported by an Artificial Intelligence (AI)-based prioritization algorithm for selective continual updating of the AWV.

03

Advance a Semi-Definite Programming (SDP) algorithm, which can transform the AWV derivation, via maximizing a recast Signal-to-Interference-plus-Noise Ratio (SINR) criterion subject to a similarity constraint, that can be recast as a convex optimization problem.

04

Advance a Quadratically Constrained Quadratic Programming (QCQP) step-down algorithm, which will compute the QCQP special class convex optimization problem in polynomial time.

05

Advance, via a multi-dimensional Space-Time Adaptive Processing (STAP) algorithmic solution set, an enhancement of the maximized SINR.

06

Advance a structural exploitation of the covariance interference matrix so as to leverage SDP Solvers and ascertain optimal pre-processors.

The first priority is signal extraction while concurrently suppressing interference as well as noise

True Adaptive Beamforming Approach

These methods selected (based upon the time involved) to enhance the beamforming and endeavor to mitigate against interference morphological adjustments (e.g., propagation channel varying, interference dynamism, etc).

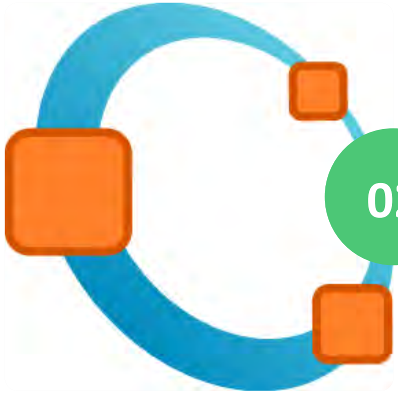
Selective Updating of the Adaptive Weight Vector, A High-Performance Semi-Definite Programming (SDP) Solver, and Reduction from Non-Deterministic Polynomial-Time Hardness (NP-HARD) to Polynomial Time for Signal-to-Interference-plus-Noise Ratio (SINR) Computations

Particular Triumvirate Approach

01

Selective updating of the adaptive weight vector

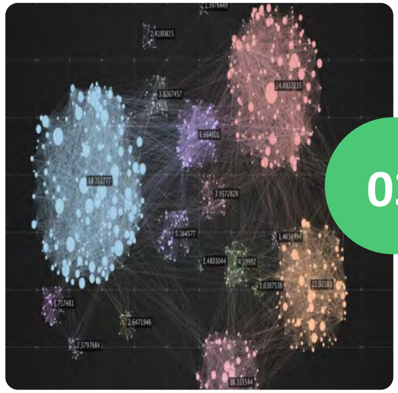
The computational availability of **Field Programmable Gate Arrays (FPGAs)** can facilitate the selective updating of the optimal adaptive weight vector (AWV).



02

A high-performance SDP Solver

The SDP solvers utilized to date have **been implemented on a GNU Octave platform**; signal processing and fuzzy logic packages were obtained, via Octave Forge, for use on GNU Octave.



03

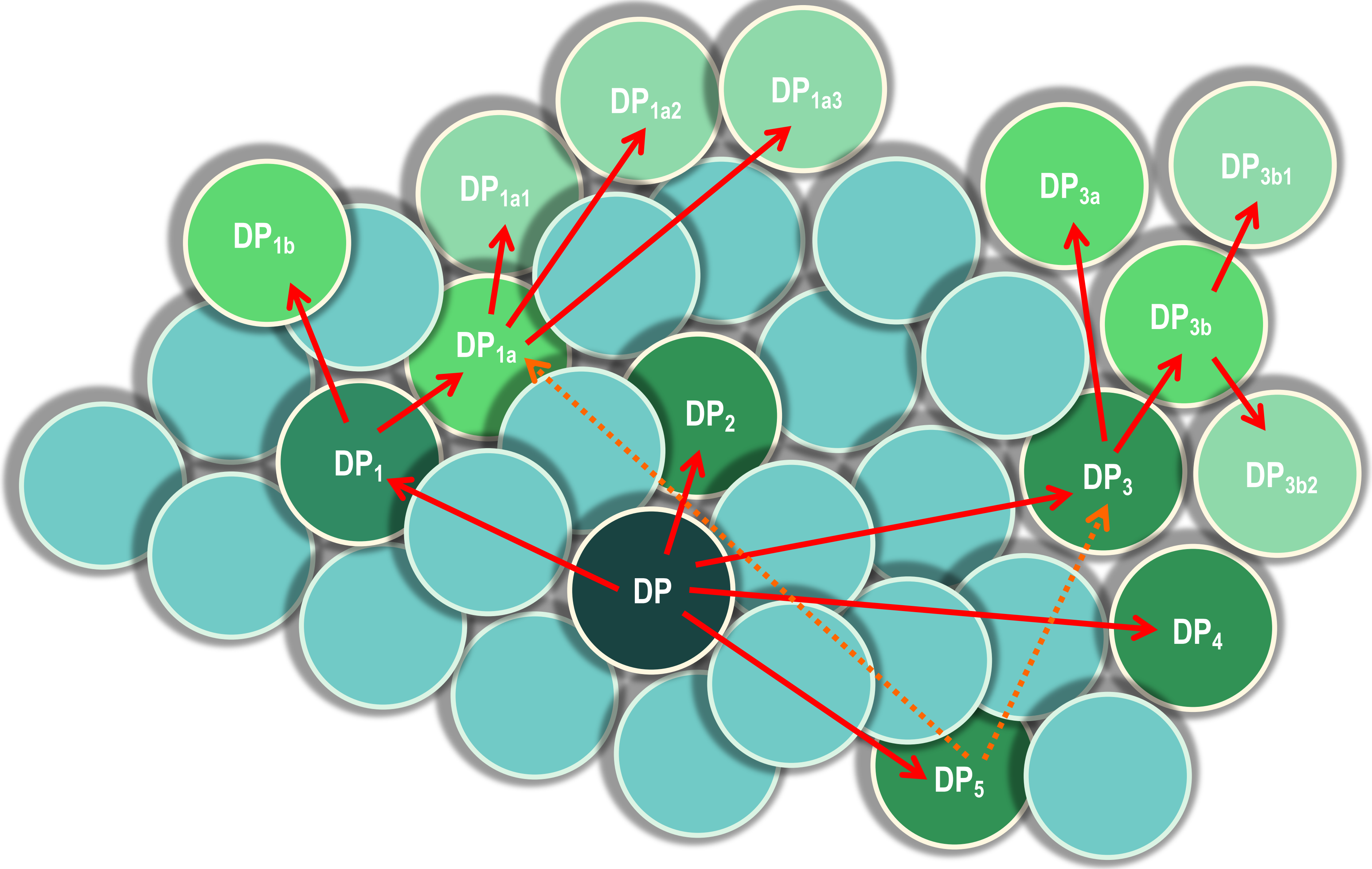
Reduction from NP-HARD to polynomial time for SINR

The computational complexity of the involved QCQP can be reduced from Non-deterministic Polynomial-time Hardness (NP-hard) to the desired optimality in polynomial time.

Enhancing the Maximized Signal-to-Interference-plus-Noise Ratio (SINR), via Space-Time Adaptive Processing (STAP)

STAP can greatly enhance performance of the RNDTC, via identification of diversity paths

The determination of the diversity paths were formulated, via certain elastic function and validated by an AI prioritization engine



Exemplar Diversity Paths (DPs)

Structure Exploitation of the Covariance Interference Matrix

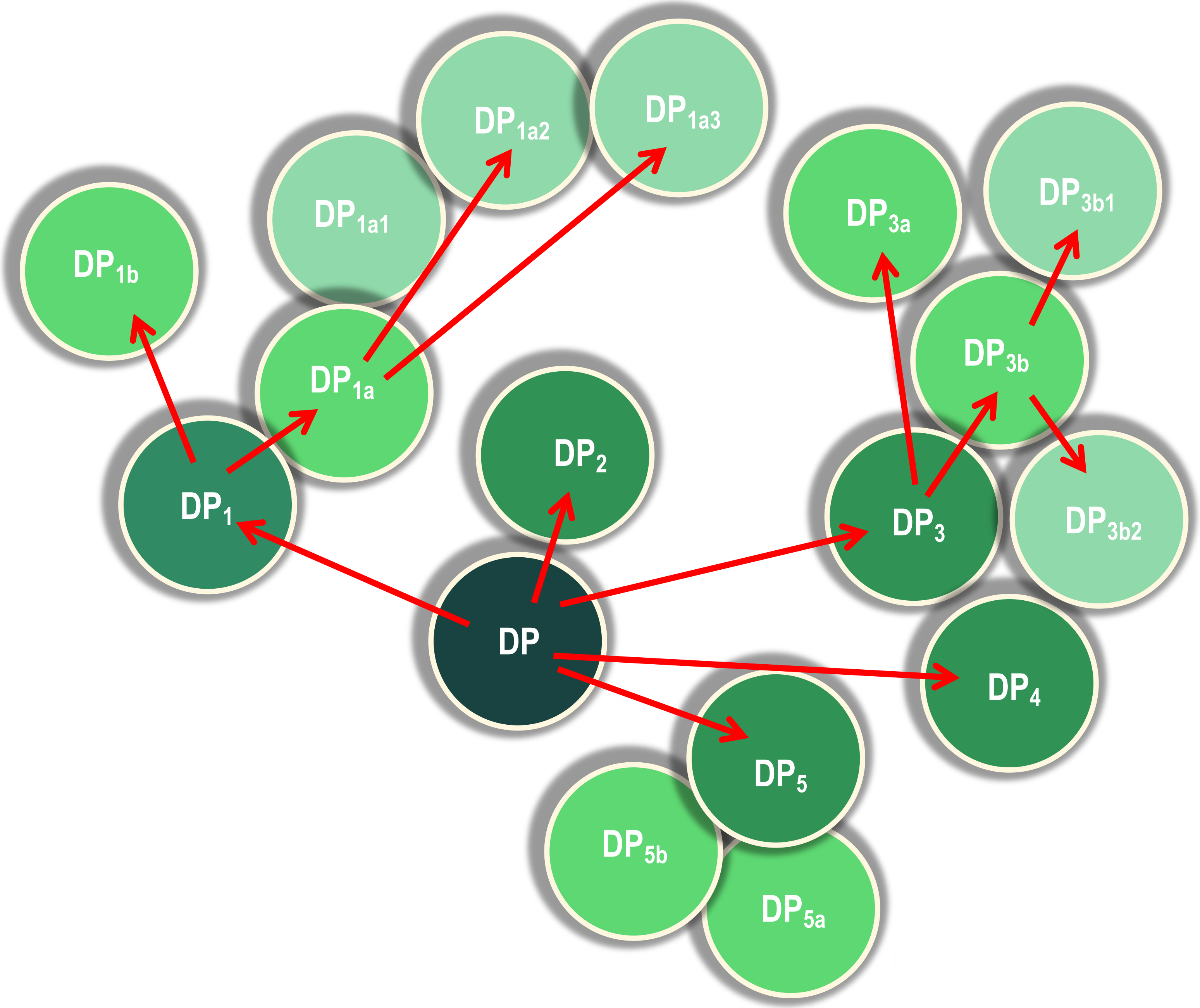
Pre-Processing

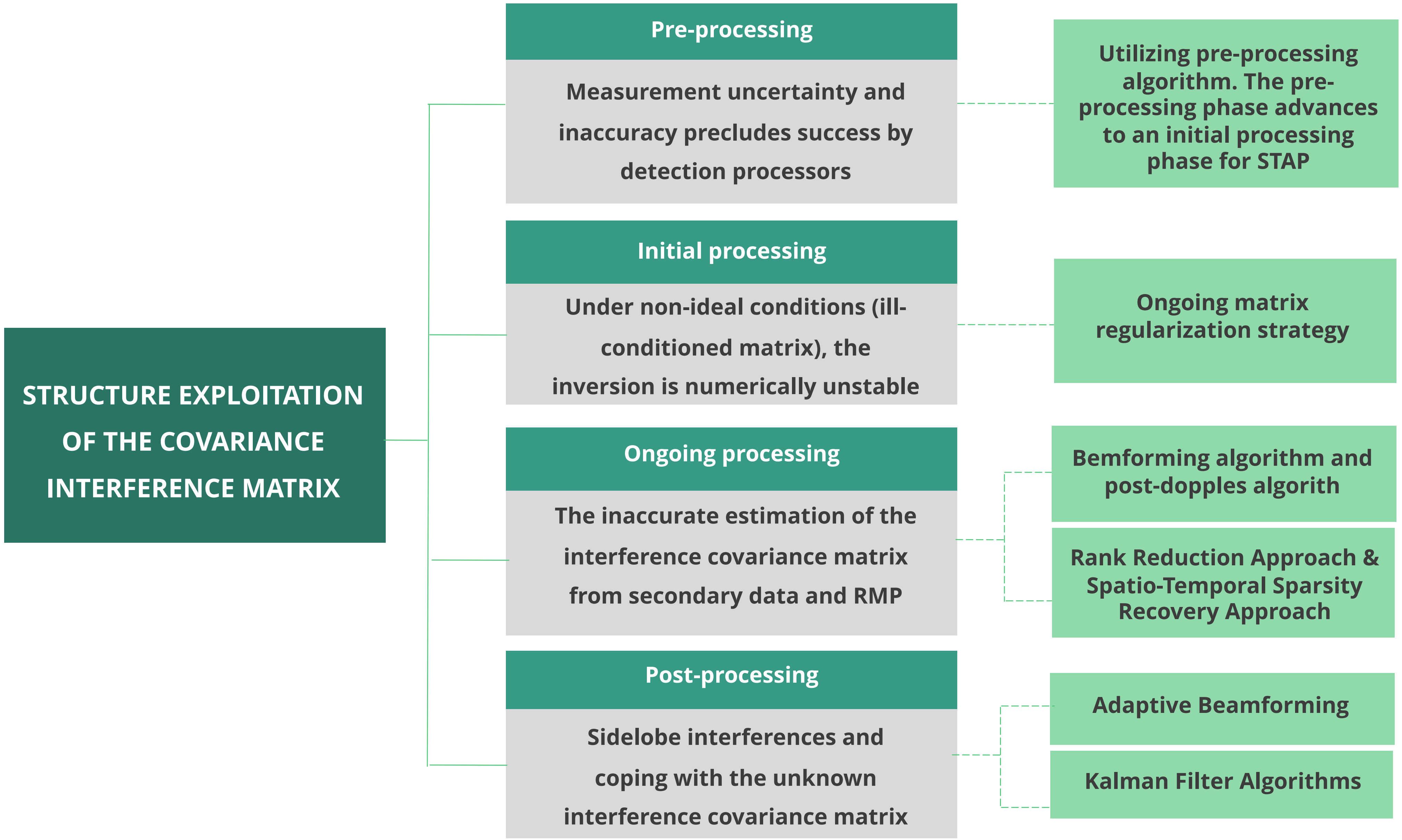
$$y = x_o^{N-1} + \xi$$

$$\min_{z \in Ho} \| x_o^{N-1} - z_o^{N-1} \|_\infty \geq \rho$$

$$\|F_N \xi\|_\infty, \alpha \in (0,1)$$

$$\mathrm{Prob}_{\xi \sim N(0, I_N)}\{\|F_N \xi\|_\infty > q_N(\alpha)\} \leq \alpha$$

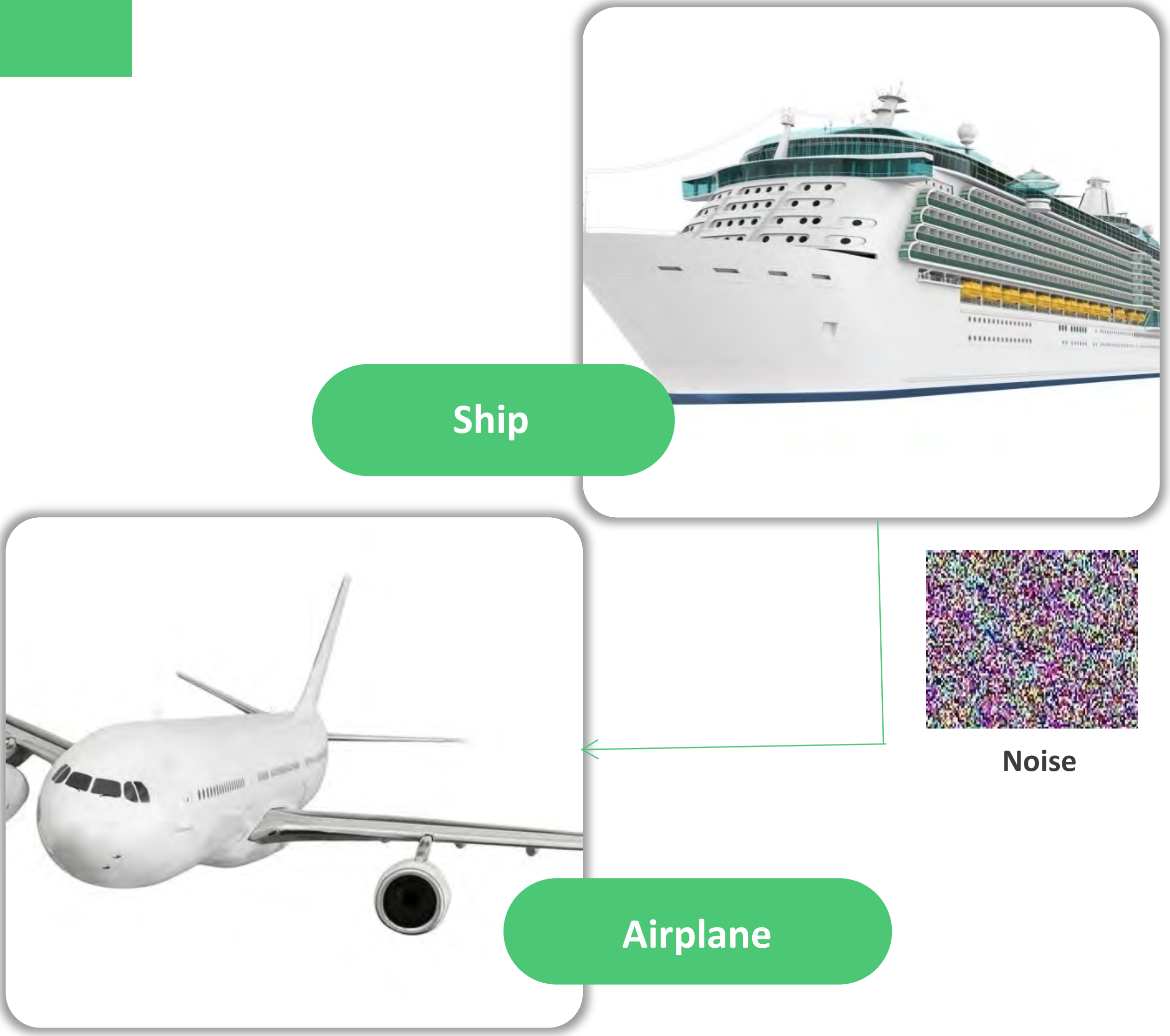




STRUCTURE EXPLOITATION OF THE COVARIANCE INTERFERENCE MATRIX
Pre-processing
Measurement uncertainty and inaccuracy precludes success by detection processors
Utilizing pre-processing algorithm. The pre-processing phase advances to an initial processing phase for STAP
Initial processing
Under non-ideal conditions (ill-conditioned matrix), the inversion is numerically unstable
Ongoing matrix regularization strategy
Ongoing processing
The inaccurate estimation of the interference covariance matrix from secondary data and RMP
Bemforming algorithm and post-dopples algorith
Rank Reduction Approach & Spatio-Temporal Sparsity Recovery Approach
Post-processing
Sidelobe interferences and coping with the unknown interference covariance matrix
Adaptive Beamforming
Kalman Filter Algorithms

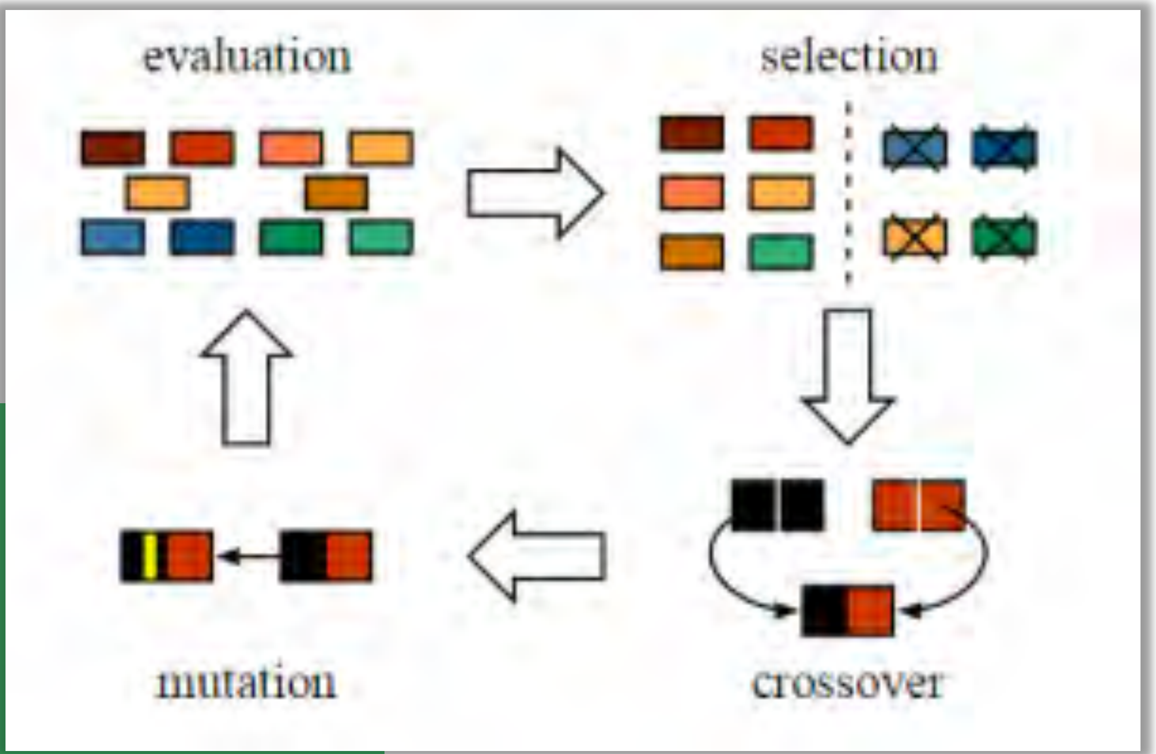
Space-Time Adaptive Processing (STAP) Heuristical Vulnerability Exploitation and an Experimental Mitigation Factor for the STAP vulnerability of Resilient Networked Distributed Tessellation Communications (RNDTC)

AMLA



STAP Heuristical Vulnerability Exploitation

The described heuristic (lower covariance value higher confidence in the detection result at time *t*; higher covariance value higher confidence in the detection result at time *t-1)* constitutes a configuration parameter, which can be exploited, particularly when time-sensitive real-time detection systems are central to the system (e.g., You Only Look Once or YOLO v3) and Adversarial Machine Learning (ML) attacks (AMLA) are involved.



Experimental Mitigation Factor for the STAP Vulnerability of RNDTC

the "Steady-State GA" (SSGA) can be construed as a discrete-time dynamic system non-generational model. The value-added proposition for the experimental mitigation factor for the STAP vulnerability of RNDTC is a compression factor that, in some instances, serves to squeeze the steady-state population towards an accelerated convergence.

The SSGA approach can indeed effectuate auto-parameter tuning so as to minimize the window for exploitation as pertains to the identified STAP heuristical vulnerability exploitation.

Preliminary Experimental Results

Preliminary Experiment Result

Preliminary experimental results indicate promise for the auto-tuning of the Steady State Genetic Algorithm (SSGA) compression factor ζ for more optimal convergence of an optimally tuned filter (or a set of near optimally tuned filters).

Auto-tuning

auto-tuning is central to this capability, and the compression factor is instrumental in dictating the rate of the steady state towards convergence.

Re-tune ζ to a lower value

one observation centers around the fact that the ability to re-tune the compression factor ζ to a lower value (i.e., <1) seems to be critical.

Principal Tuning Result (PTR)

$$\mathrm{PTR} = [F_{t+1} - F_t] < F_t\,(e^{-\lambda t} - 1)$$

CONCLUSION

The SSGA approach to effectuate auto-parameter tuning so as to minimize the window for exploitation as pertains to the identified STAP heuristical vulnerability exploitation. Proxy use cases (e.g., electrical grid sector) proved useful for auto-tuning experimentation as pertains to the compression factor, which dictates the efficacy of the convergence upon an optimally tuned filter (or a set of near optimally tuned filters).

FUTURE WORK

Future work will involve furthering the exploration of the SSGA compression factor and conducting more in-depth research into the SDP solver(s) atop the customized M-GNU-O platform.

Thank you