RESEARCH REVIEW

An Evolutionary Game Theory Approach for Intelligent Patrolling
http://www.sciencedirect.com/science/article/pii/S1877050912006357

Abstract:

The issue of border patrolling is paramount to the overall process of securing a country, and when examined as a network traversal problem, is considered an NP-Hard problem (Non-deterministic polynomial hard time). Patrolling can be thought of as the act of traveling an area in regular intervals in order to secure it against different threats which can also be thought of as multi-agent actions for modeling purposes. This paper presents a hybrid method of addressing this problem that combines an **evolutionary approach** and **game theory concepts** in order to define a **multi-agent patrolling strategy** that **simultaneously optimizes** three key concerns : *maximum idleness*, *infiltration ratio*, and *total patrolling cost*.

Definitions:

- Maximum idleness - the biggest idleness (amount of time that a node (patrol checkpoint) is not visited) value that occurred during the entire patrolling process for all nodes for all the agents.
- Infiltration ratio - the average number of times the attackers infiltrated (was not caught by the patrol)
- Total patrolling cost - summation of all the costs of all the agents engaged in patrol.

Challenges:

- NP-Hard graph traversal problem - The patrolling problem is an NP-Hard problem that is very difficult to solve as the size of the area to be covered grows.
- Predictability - one of the most important challenges that border patrol agencies face is predictability. Adversaries can observe security strategies over time and exploit any predictable behavior to their advantage.
- Mutual Learning - both security forces and adversaries will necessarily learn from each other during their course of engagement, which is a issue to address when modeling behaviors.

Approach:

This paper considers the patrolling problem as a **multiple objective optimization problem**, where three different objectives (*maximum idleness*, *infiltration ratio*, and *total patrolling cost*) will be optimized simultaneously. The method proposed to do so is a **hybrid algorithm that combines an evolutionary approach (think genetic algorithms) with game theory concepts** in order to select an optimal multi-agent patrolling strategy.

Evolutionary Game Theory Algorithm:

- Note: Evolutionary (genetic) algorithms have proven to be able to perform well when solving complex NP-Hard problems.

The algorithm is a hybrid of genetic and game theory algorithms and is outlined as follows:

Initialization and Evaluation

- Initial populations of both attackers and defenders are randomly generated, objectives are initialized, graphs generated.

Selection

- The objective of this stage is to select the best solutions for each population (defender and attacker) , undergo crossover (controlled genetic mutations) and generate the population for the next generation. ***The selection process incorporates the game theory strategies differently for each population.***
- ***Attacker*** - in order to select those fit to undergo crossover (genetic mutation) - a game between must be played and solved with a strategy. The idea is to select those dominant strategies (defined as those which will win no matter how the opponent plays), and eliminate the weaker strategies.
- ***Defender*** - Three fitness functions are employed, (a) a dominance count-based metric [select the most dominant individuals], (b) a distance based metric [intended to maintain population diversity], and (c) an aggregation function that sums the previous two fitness functions to place equal emphasis on each.

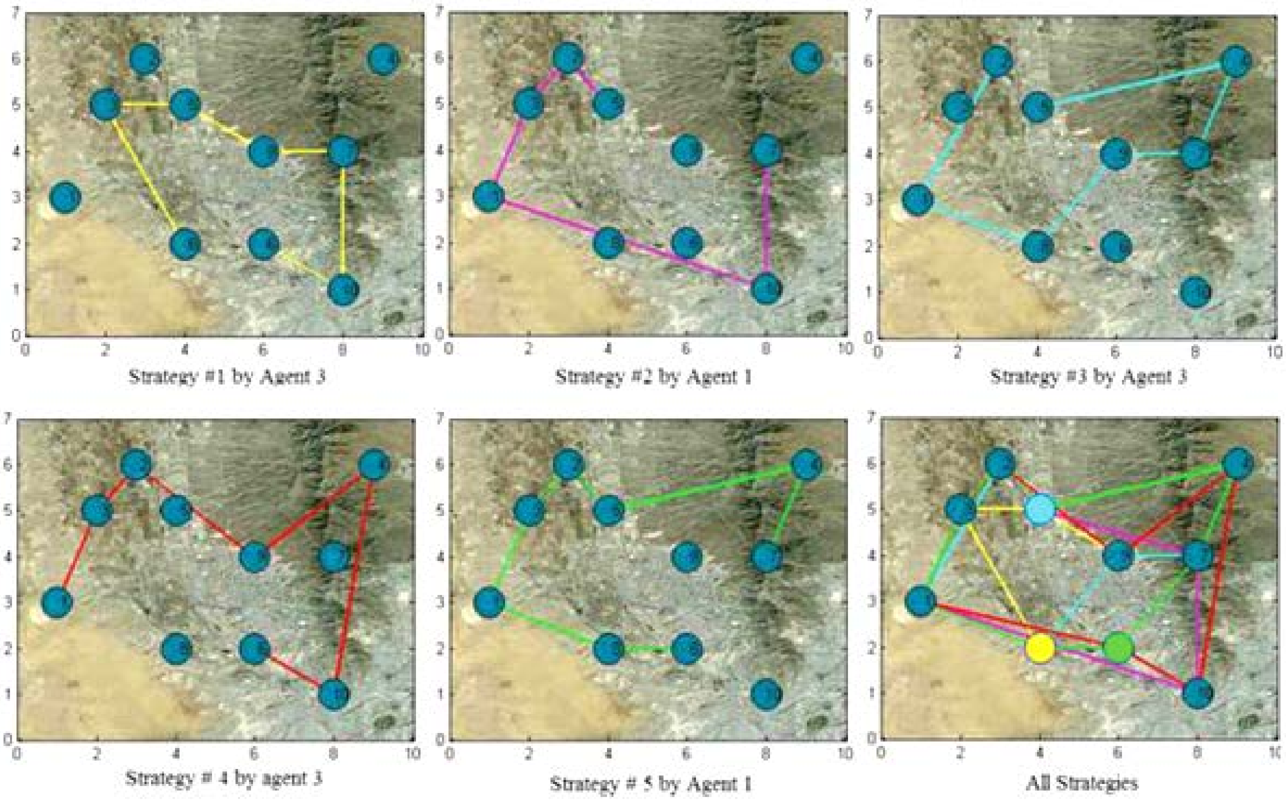
Reproduction

- Current ranked solution (from the previous steps) are recombined in a method called sub-system rotation crossover (SURC), that creates the next generation of population. The new generation is effectively formed using "elite" parents.

Execution:

Simulations were constructed using a network of 10 nodes, 5 strategies, and 5 different types of agent (with different characteristics and attributes), population side =100, Elitism = 25%, Crossover 75%, Mutation = 1% over 50 generations.

The resulting solution routes are below along with the composite solution accounting for all agents.



Strategy #1 by Agent 3 | Strategy #2 by Agent 1 | Strategy #3 by Agent 3

Strategy # 4 by agent 3 | Strategy # 5 by Agent 1 | All Strategies

Concluding Remarks:

This set of solutions (non-dominated Pareto solutions) contains a variety of solutions with multiple objectives which provide multiple options to the decision maker - all of which optimize the three different conflict objectives. There is still considerable work to be undertaken on this approach, comparisons with other methods, testing the scalability of the model, and the performance when more characteristics are added to the attacker and defender.