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2025 - PDR - 2FK-XHB - Sensor Scheduling in Intrusion Detection Games with Uncertain Payoffs - jbhargav@purdue.edu - Jayanth Bhargav

Sensor Scheduling in Intrusion Detection Games with Uncertain Payoffs

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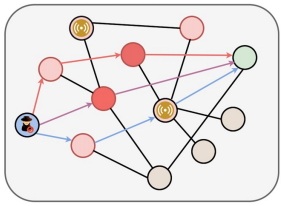
Overview

Goal: Efficiently schedule a set of sensors for monitoring and intrusion detection
Approach: Model the interactions between defender and intruder as a 2-player game
Key Challenges:

- Exponentially many scheduling strategies for defender - Combinatorial strategy space
- Unknown sensor models - Need to learn and adapt scheduling strategies online



Problem Formulation

Player 1 – Defender

- Strategy space: I; $m = |I|$
- Mixed-Strategy: $x \in \Delta_{|I|}$
- Strategy costs: $c_i \in \mathbb{R}_{>0}$; $i \in I$
- Payoff Matrix: $A' \in \mathbb{R}^{m \times n}$

$$A'_{ij} = \log(p_{miss}(i,j)) + c_i$$

- Defender's Optimization Problem

$$\min_{x \in \Delta_{|I|}} x^T A' y$$

Game
$\mathcal{G}' = \{A', B'\}$

Player 2 – Intruder

- Strategy space: J; $n = |J|$
- Mixed-Strategy: $y \in \Delta_{|J|}$
- Strategy costs: $r_j \in \mathbb{R}_{>0}$; $j \in J$
- Payoff Matrix: $B' \in \mathbb{R}^{m \times n}$

$$B'_{ij} = -\log(p_{miss}(i,j)) + r_j$$

- Intruder's Optimization Problem

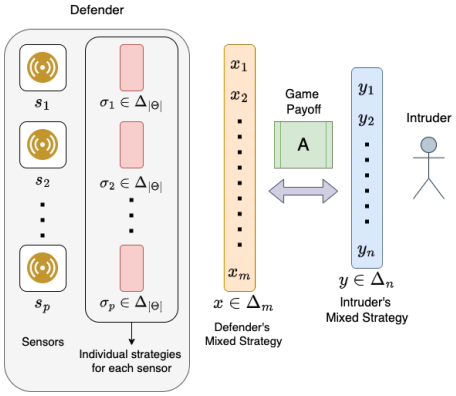
$$\min_{y \in \Delta_{|J|}} x^T B' y$$

Intruder vs Defender Game

- Defender: Schedules a set of sensors to monitor nodes
- Intruder: Chooses a path from a set of paths in the network/graph
- Game Payoff: Probability of Missed-Detection & Strategy Cost

Main Results

- Distributed Weighted Majority (DWM) Algorithm
  - Fast and scalable algorithm to estimate Nash equilibrium
  - Theoretical guarantees for convergence
  - Individual scheduling strategies for each sensor
- Online Learning and Adaptation of Strategies
  - Upper Confidence Bound (UCB) style algorithm for learning the game
  - Online learning under bandit feedback from sensor detection events
  - Order optimal regret bounds: $\tilde{\mathcal{O}}(\sqrt{|\mathcal{S}|^2|\Theta||J|T})$



Strategy Space	Running Time (seconds) Linear Program	Weighted Majority	Distributed Weighted Majority
16 x 50	3.22	2.73	**2.68**
64 x 50	7.90	3.04	**2.65**
256 x 50	24.88	6.09	**4.66**
1024 x 50	75.72	12.15	**6.99**

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