An Evolutionary Game for Integrity Attacks and Defenses for Advanced Metering Infrastructure

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Outline

- Motivation
- AMI as a dynamic tree structure
- Evolutionary integrity game
- Usage example
- Summary & future work

Motivation

- Data integrity is one of the concerns
  - Deng, R., Xiao, G., Lu, R., Liang, H., Vasilakos, A.V.: False data injection on state estimation in power systems attacks, impacts, and defense: A survey.IEEE Transactions on Industrial Informatics 13(2), 411{423 (April 2017).
- Message authentication schemes are computing-intensive
- Resources
  - numerous wireless devices with limited resources
- Trading off security and computational constraints
  - AMIs must carefully decide when, what, and how to authenticate

Why use evolutionary game?

- Multiple adversaries can coexist, cooperate and evolve
  - To meet the challenges of possible intelligent cooperation between adversaries and their ability to learn from each other experience
- Defenders can also cooperate and learn from each other experience the effectiveness of defensive strategies should be addressed in multiple defender scenarios
  - To help nodes of an AMI to cooperate and to work out a joint protection,

Why use evolutionary game?

- Not a statistic approach
- EG models a dynamic in populations of players
  - populations evolve according to the relative success of individual strategies compared to the overall population

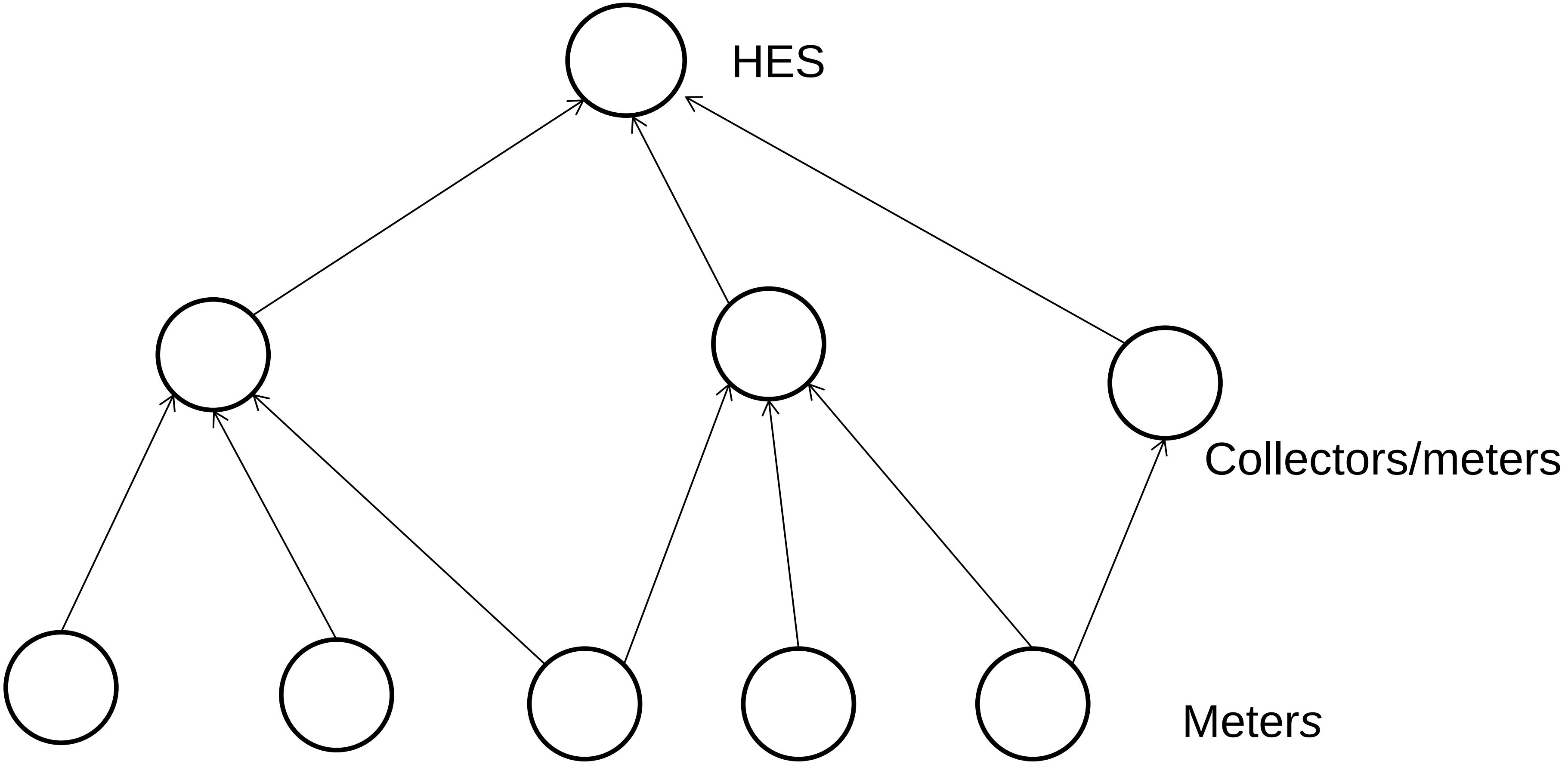
Two key elements:

- Evolutionary Stable Strategy x is robust against any alternative mutant strategies ϵ

$$U(x, (1-\epsilon)x + \epsilon y) \geq U(y, (1-\epsilon)x + \epsilon y)$$

- Replicator equation governs evolution of populations

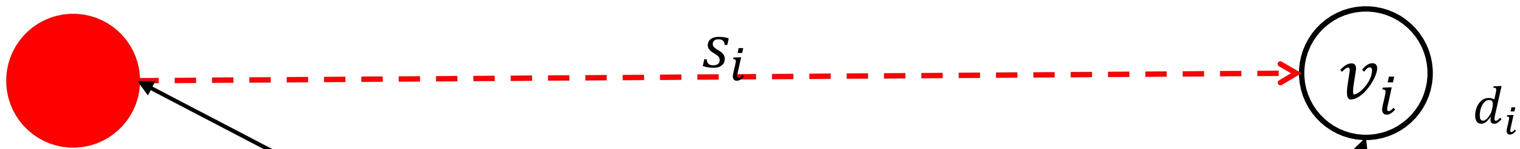
AMI as a dynamic tree structure



EG formulation: integrity strategy space

Attacker *k (Cost to attack)*

Node *i (Cost to defend)*



$$S = \left\{ s \in [0,1]^N : \sum_{i=1}^{N} s_i \leq 1 \right\}$$

$$D = \left\{ d \in [0,1]^N : \sum_{i=1}^{N} d_i \leq 1 \right\}$$

Game formulation

Attackers

Defenders

Probability distributions over strategy spaces

$$\sigma(t) = (\sigma_0(t), \ \ldots, \sigma_1(t)) \qquad \delta(t) = (\delta_0(t), \ \ldots, \delta_n(t))$$

Expected utilities

$$U_A(s_i, \delta) = \sum_{j=0}^{N} \delta_j(t) U_A(s_i, d_j) \qquad U_D(d_i, \sigma) = \sum_{j=0}^{N} a_j(t) U_D(s_j \, d_i)$$

Average expected utilities

$$U_A(\sigma, \delta) = \sum_{i=0}^{N} \sigma_i(t) \, U_A(s_i, \delta) \qquad U_D(\sigma, \delta) = \sum_{i=0}^{N} \delta_i(t) \, U_D(\sigma, d_i)$$

Replicator Equation

Attackers at time *t*:

$$\frac{ds_i(t)}{dt} = (U_A(s_i, \delta) - U_A(\sigma, \delta))s_i(t)$$

Expected utility for strategy *i*

Average expected utility

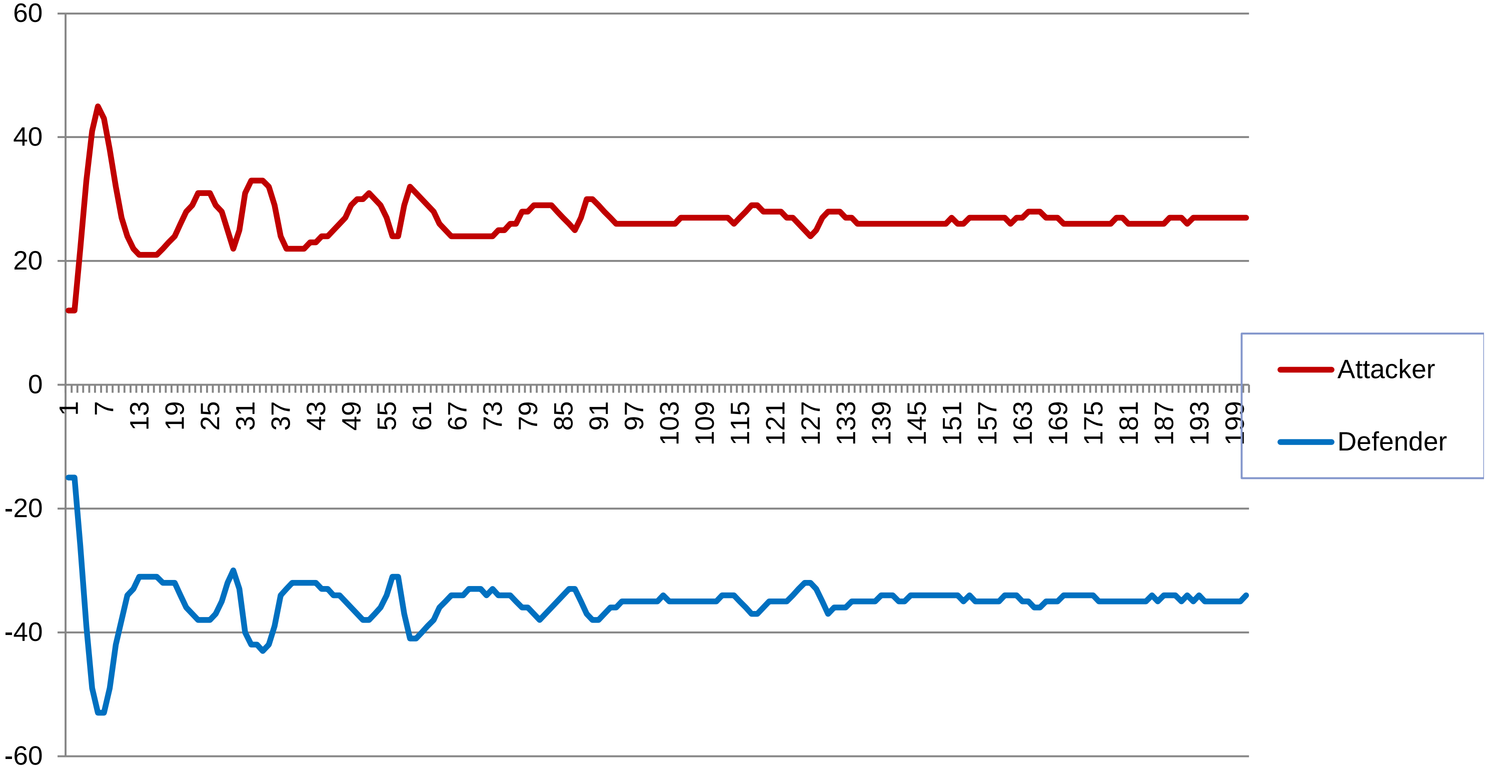
Defenders at time *t:*

$$\frac{dd_i(t)}{dt} = (U_D(d_i, \sigma) - U_D(\sigma, \delta))d_i(t)$$

Usage example

Node Number	Value	Cost of attack	Cost of defense
1	40.0	10.0	3.0
2	20.0	6.0	2.0
3	22.0	6.0	2.0
4	5.0	1.0	0.8
5	10.0	1.0	0.8
6	9.0	1.0	0.8
7	9.0	6.0	0.8
8-15 (meters)	2.0 – 3.0	0.1	0.8

Evolution of average utilities



Summary and future work

- Paper in progress: Evolutionary Game for Integrity Attacks and Defenses for Advanced Metering Infrastructure
  - Larger trees for AMIs
  - Dynamics as option for defender's strategy space
  - Game analysis security levels/strength/weakness for attacker and defender currently
- How to use the results and how to adapt defense in real time?
- Combine with machine learning