CPS: Breakthrough: Towards a Science of Attack Composition, Mitigation and Verification in Cyber Physical Systems: A Passivity Based Approach (CNS-1446866)

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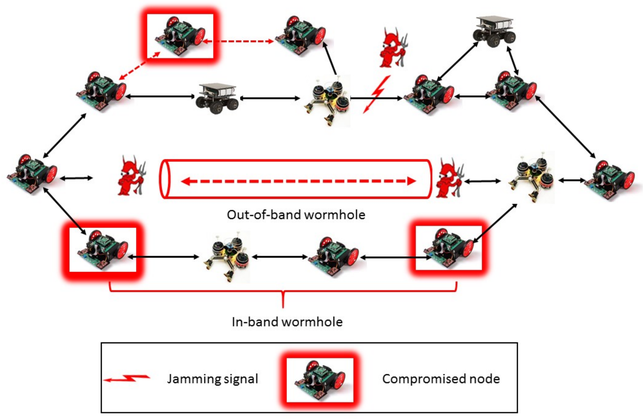
Need for Science of CPS Security

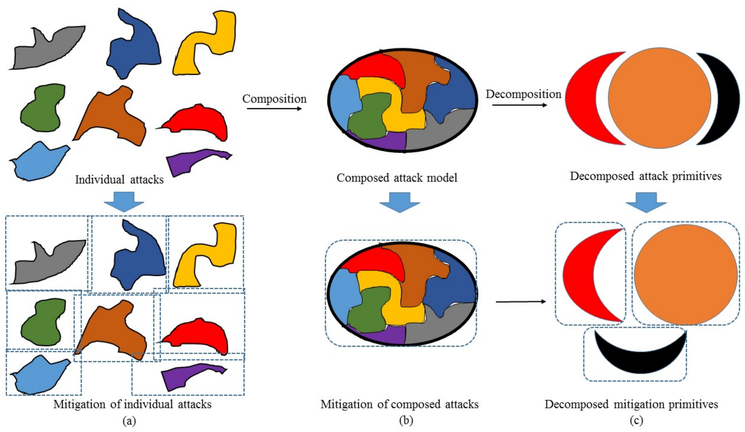


- CPS are inviting targets for intelligent, persistent attacks
- **Composition of multiple attacks** and **development of mitigation strategies** are open problems in cyber security
- Need to **provide verifiable guarantees** of CPS performance and security in the presence of cyber attacks

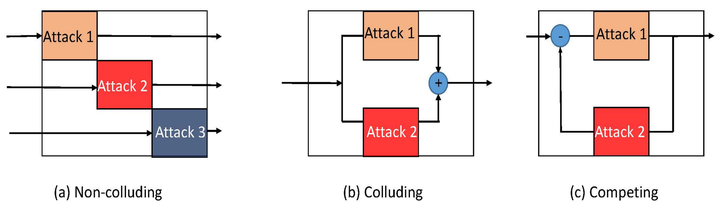
Scientific Questions Addressed

- How to **model intelligent, persistent attacks** and their impact on CPS?
- How to **compose multiple attacks** and develop efficient mitigation strategies against composed attacks?
- How to **verify the mitigation strategies** provide required performance, safety and security of CPS?

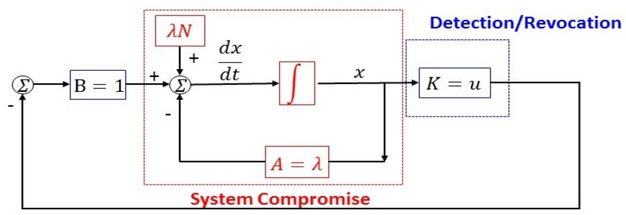
Our Passivity Based Approach



- Provides **composition rules** of multiple adversary models
- Enables **identification of new attack primitives** via decomposition of composed attacks
- Leads to **seamless integration** into dynamical models of CPS
- Adaptive **incorporation of newly-discovered attacks** into composed adversary mode
- Develop techniques for **verification** of passivity-based adversary models and mitigation via **approximate bisimulation**

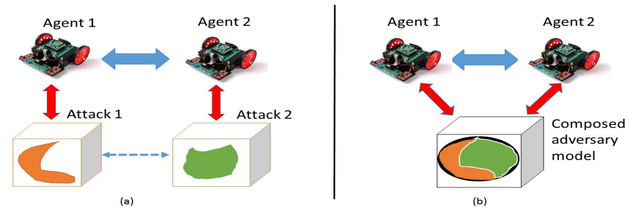


Thrust 1: Passivity Modeling of Individual Attacks and Mitigation



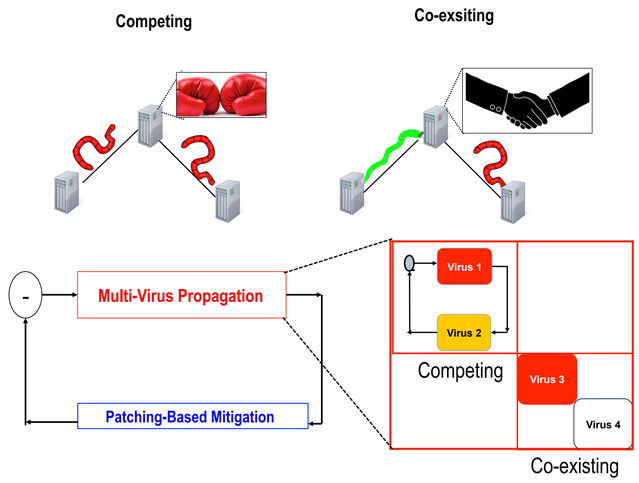
- Formulate **passive dynamical models** representing impact of attack on CPS
- **Identify class of cyber-attacks** that admit passive dynamical representation
- Model the **time-varying mitigation strategy** as passivity dynamical system
- Design mitigation strategy to **guarantee security properties** of CPS

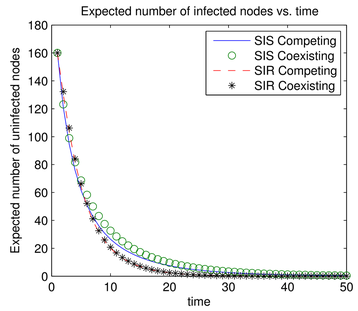
Thrust 2: Passivity-Based Composition of Adversary Models and Mitigation



- **Compose attacks** by non-colluding, colluding, and competing adversaries
- Compose attacks targeting distinct, interdependent CPS components
- **Decompose a composed adversary** model into attack primitives
- **Develop efficient mitigation strategies** against composed

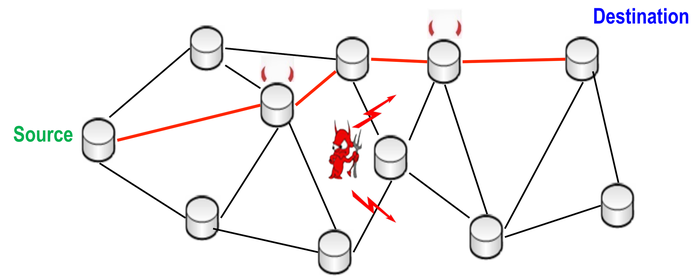
A Passivity Framework for Modeling and Mitigating Multi-Virus Propagation





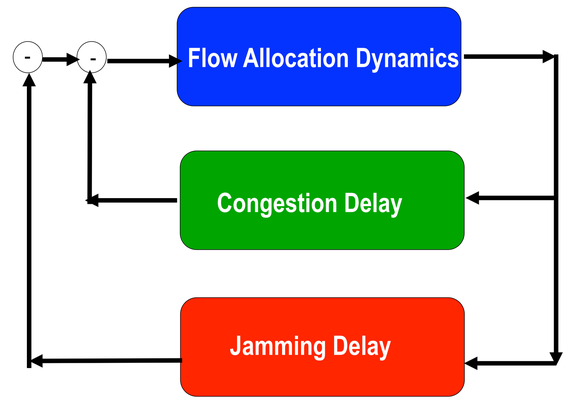
- Developed **composition rules** for competing and co-existing viruses
- Feedback interconnection of multi-virus propagation and mitigation
- Characterized required patching rate to remove viruses as the **passivity index** of the propagation dynamics

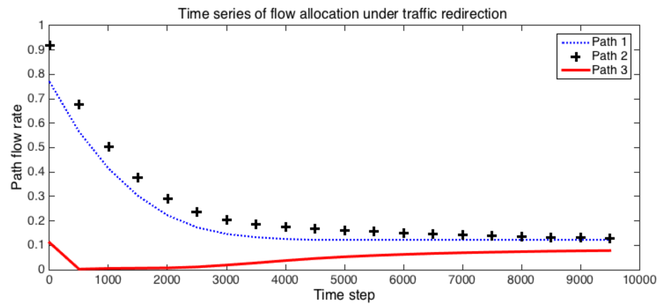
Flow Redirection Attack via Jamming



- Source-destination flows traverse multiple relays
- Adversary controls set of **malicious relays**
- Malicious relays drop, replay, delay, or re-order routed packets
- **Flow redirection attack:** Jam non-malicious relays
- Network flows re-routed through malicious relays

Passivity-Based Approach for Modeling Flow Redirection Attack





- Developed control-theoretic model of flow allocation, congestion delay, and jamming delay induced by adversary
  - Interaction between components modeled as negative-feedback interconnection of **passive dynamical systems**
- Developed jamming strategy to reach desired flow allocation via **passivity-based approach**

References

[1] P. Lee, A. Clark, L. Bushnell, and R. Poovendran, "A Passivity Framework for Modeling and Mitigating Wormhole Attacks on Networked Control Systems," *IEEE Transactions on Automatic Control*, 2014.

[2] P. Lee, A. Clark, B. Alomair, L. Bushnell, and R. Poovendran, "Jamming-Based Adversarial Control of Network Flow Allocation: A Passivity Approach," American Control Conference, 2015

[3] P. Lee, A. Clark, L. Bushnell, and R. Poovendran, "Passivity Framework for Composition and Mitigation of Multi-Virus Propagation in Networked Systems," American Control Conference, 2015

[4] P. Lee, A. Clark, B. Alomair, L. Bushnell, and R. Poovendran, "A Host Takeover Game Model for Competing Malware," Conference on Decision and Control (CDC), 2015