Resilient Operations of Unmanned Aerial Vehicle Systems

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September 27, 2018

Motivation

Figure Courtesy of NASA Ames Research Center

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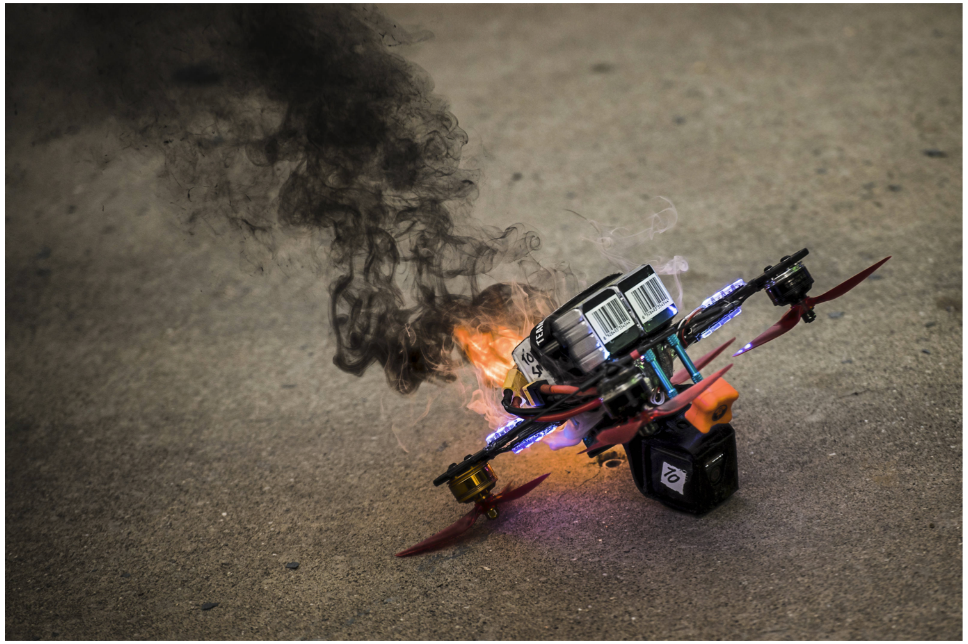
Resilient UAV System (UAS) in Literature

- UAS is a System of Systems (SoS). Many concepts and research have been derived from the SoS perspective.
- Resilience has different definitions in different domains. In UAS, we adopt the DoD notion: Repel/Resist/Absorb, Recover, Adapt, and Broad Utility.
- General approach: adding resources, adding margins, and increasing capacities.
- UAV is an aircraft.
- UAS is a transportation system.

Resilience in UAS



- Efficiency (under normal operational conditions)
- Robustness (to drone failures/perturbations)
- Security (under cyberattacks)

Figures Courtesy of NASA, Red Bull Content Pool, SecurityIntelligence

Efficiency

- Challenges
  - Lack of realistic and tractable models that captures the UAV traffic features
  - Lack of metrics and analytic tools to analyze the UAS performance
  - Control and management of both manned and unmanned aerial vehicles
- Approach (key elements)
  - Modeling: *stochastic queuing models*, fluid queuing models, PDE-based models
  - Vehicles as customers, airspace/airport as servers
  - Built on the PI Sun's past research in air traffic control and ground traffic ramp metering
    - Network layer: routing under capacity perturbations
    - Link layer: demand management and ramp metering

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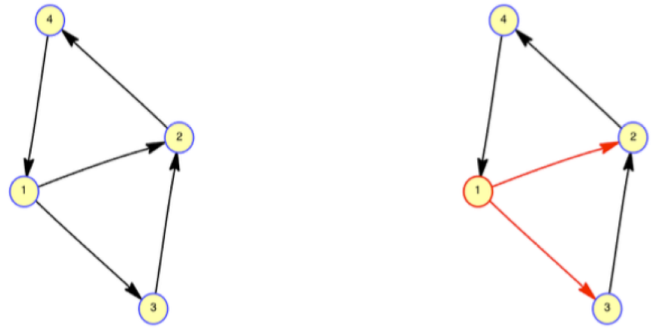
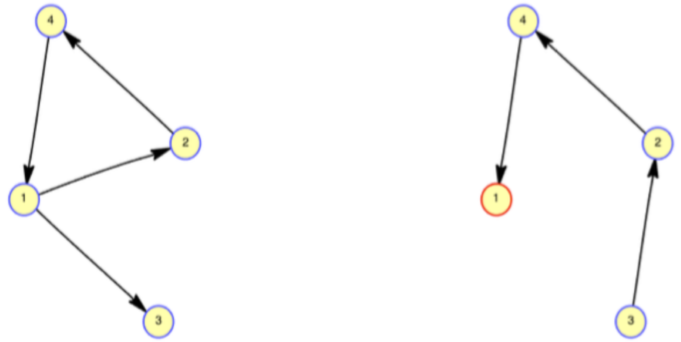
Robustness

- Focus on robustness the UAS network
  - Loss of/unreliable communication link; malicious attacked communication channels
  - Loss of individual UAVs in the network
- Approach
  - Complementary to Mou/Sundaram's work on consensus, we study from the perspective of distributed optimization under aforementioned attacks by making some reasonable assumptions.



(a) Network at odd iterations (b) Network at even iterations



Assumption 1

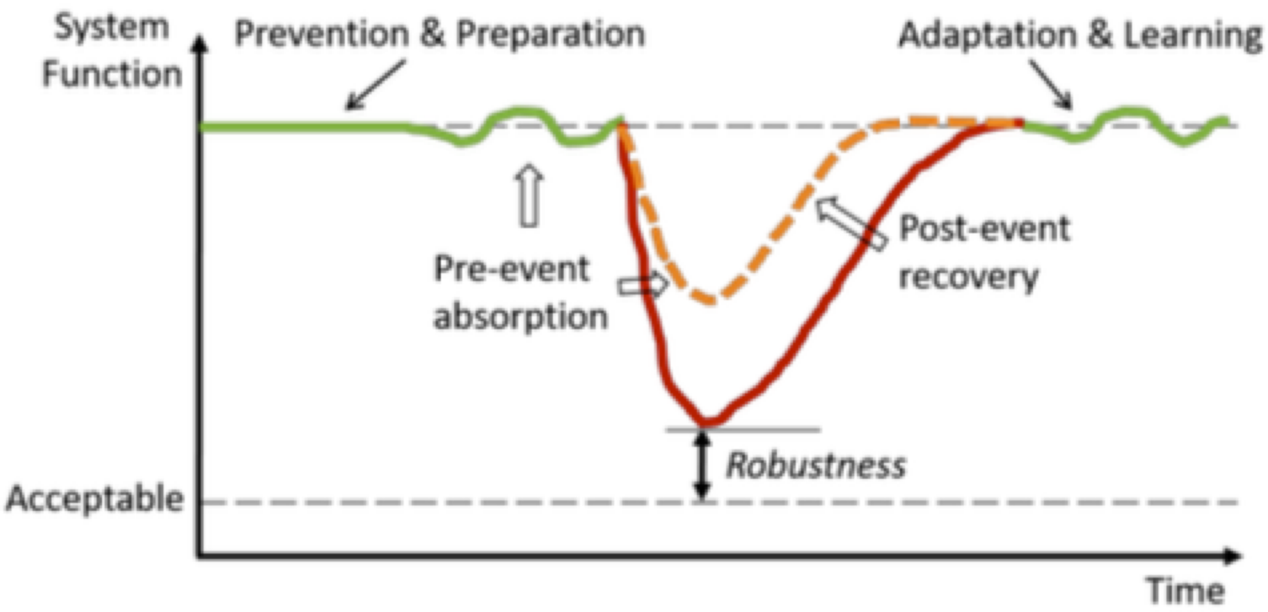
There exists an integer $T > 0$ such that

$$\cup_{k=t}^{t+T-1} \mathcal{N}^k = \mathcal{V}, \quad \forall t \in \mathbb{N}_+,$$

where $\mathcal{N}^k = \{i \mid \text{node } i \text{ is not under attack}\}$ denotes the set of normal nodes at iteration k, and $\mathcal{V} = \{1, 2, \cdots, N\}$ denotes the set of all nodes.

Performance (Metric) Function

- Absorptive capacity: the ability of the system to endure a disruption without significant deviation from normal operating performance
- Adaptive capacity: the ability of the system to adapt to a shock to normal operating conditions
- Restorative capacity: the ability of the system to recover quickly and at low cost from potentially disruptive events



Expected Outcomes

- Modeling of resilient UAS → General resilient models
  - Queuing models?
- Resilient control of UAS → Resilient control of networked dyn. sys.
  - Provable, scalable
- Simulation tools

Questions?

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Figure Courtesy of NASA Ames Research Center