Raven: Automated Discovery of Semantic Attacks in Multi-Agent Navigation Systems

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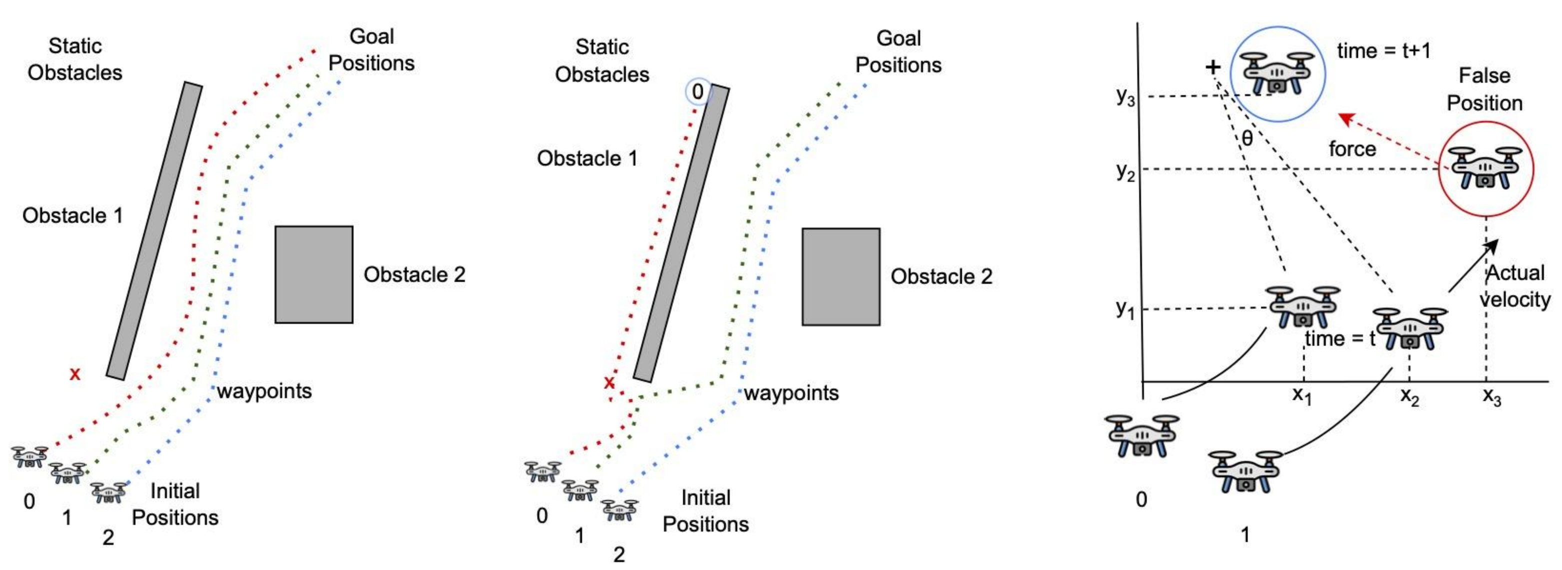
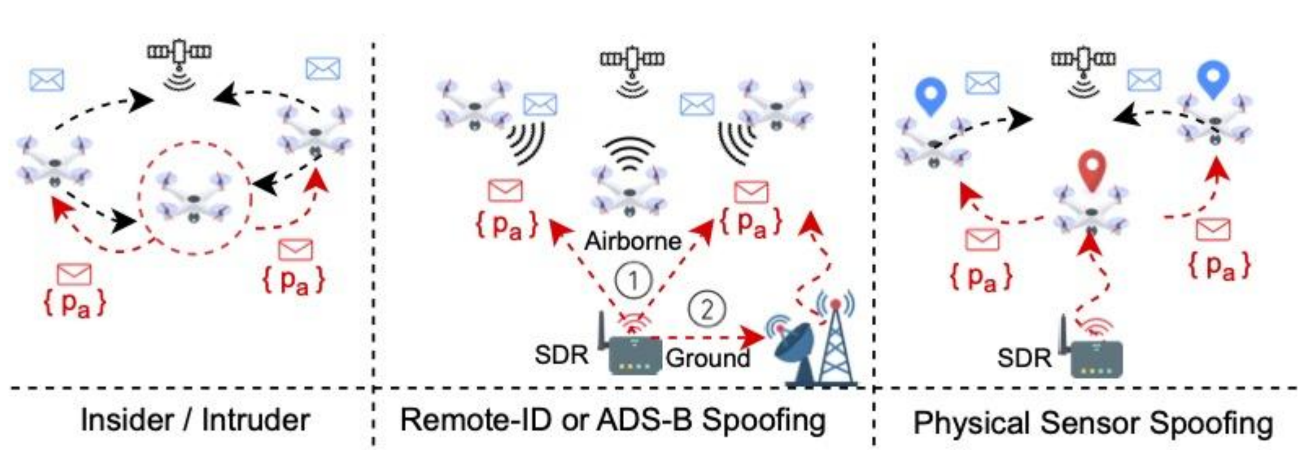
Introduction

- Autonomous multi-robots (AMRs) rely on collision avoidance algorithms for surveillance, logistics, and security operations.
- However, these systems are vulnerable to False Data Injection Attacks (FDIAs).
- Existing methods fail to consider complex multi-robot dynamics and the full spectrum of attacks.



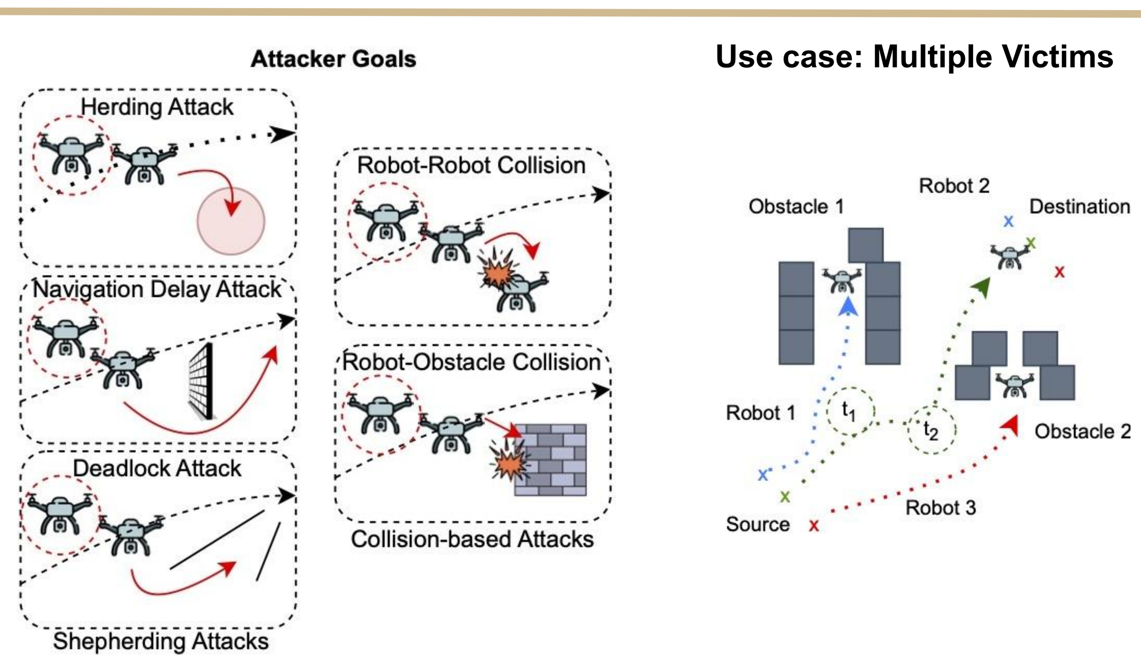
Threat Model



- Insider/Intruder: A malicious robot within the swarm injects false position data into the network.
- Remote ID/ADS-B Spoofing: The attacker exploits unauthenticated and unencrypted broadcast protocols to transmit fake robot locations.
- Sensor Spoofing: The attacker spoofs GNSS signals, causing the target robot to report an incorrect position.

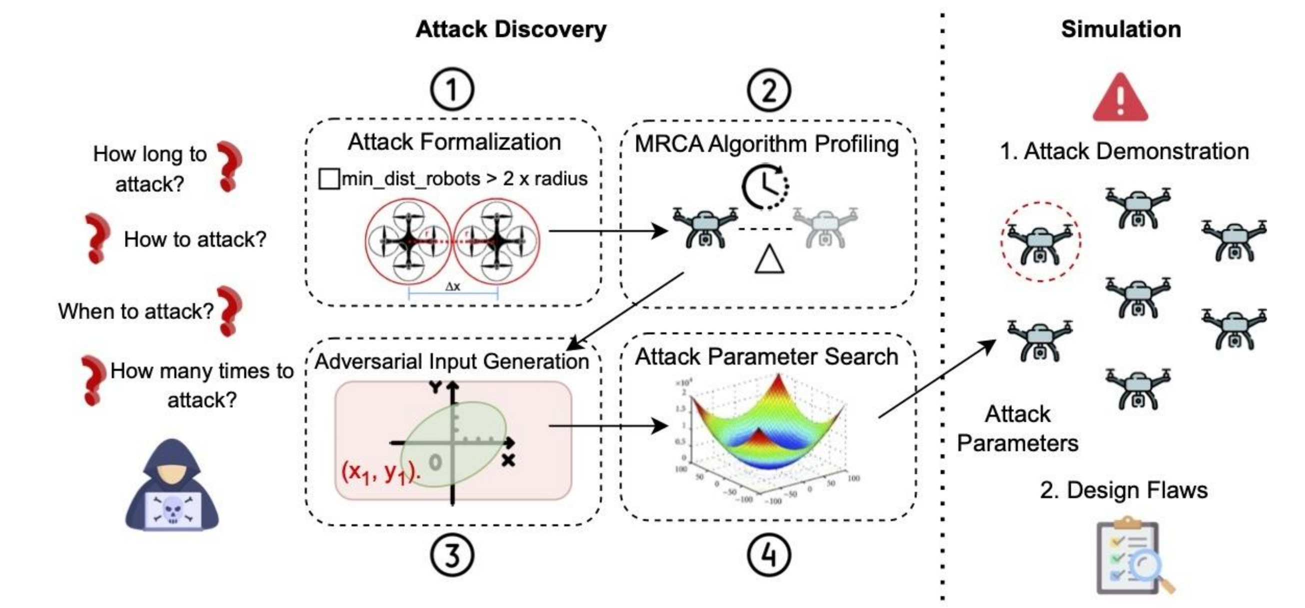
Attacker Goals

- Herding: Forcing a victim into attacker-defined area.
- Deadlock: Immobilizing robots for certain time.
- Navigation Delay: Forcing a victim to take a longer, suboptimal route.
- Robot-Robot Collision: Inducing collisions between robots.
- Robot-Obstacle Collision: Inducing collisions with obstacles.



RAVEN Overview

- Uses Signal Temporal Logic (STL) for formal attack specification.
- MRCA algorithm profiling.
- Employs stochastic optimization for finding stealthy attack parameters.
- Minimize detection by maintaining spatio-temporal consistency and sensor noise ranges.



Evaluation Results

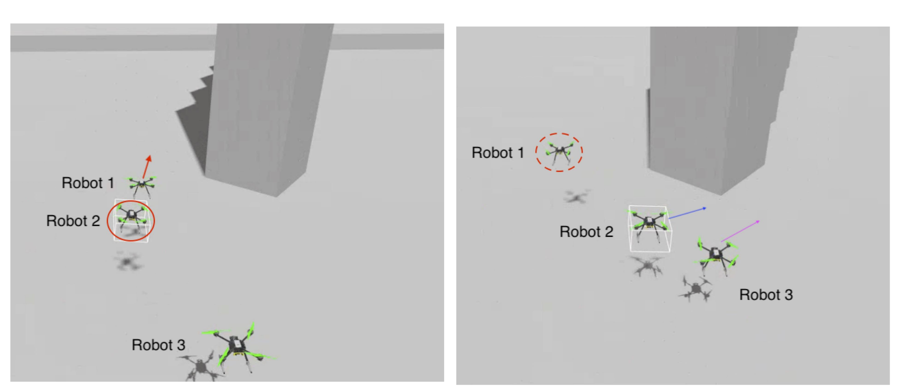
Attack Goal	Benign Case	Attack Discovery	Min # Injections	Attack Plan Time	Root Cause†
Experiments on ORCA					
Robot-Robot Collision	0/10 (0%)	10/10 (100%)	1	2.38 s / 2.6 s / 2.94 s	HR-ICM-PTT-FC
Robot-Obstacle Collision	0/10 (0%)	10/10 (100%)	1	2.5 s / 4.2 s / 4.6 s	HR-ICM-PTT-FC
Herding	0/10 (0%)	10/10 (100%)	1	1.97 s / 2.26 s / 2.53 s	HR-ICM-PTT
Deadlock	0/10 (0%)	10/10 (100%)	1	1.22 s / 2.2 s / 2.44 s	HR-ICM-PTT
Navigation Delay	0/10 (0%)	10/10 (100%)	1	1.01 s / 3.35 s / 5.63 s	HR-ICM-PTT
Experiments on GLAS					
Robot-Robot Collision	0/10 (0%)	10/10 (100%)	1	7:39 s / 7:58 s / 8:54 s	ICM-PTT-LA
Robot-Obstacle Collision	0/10 (0%)	10/10 (100%)	1	8:4 s / 10:2 s / 14:8 s	ICM-PTT-LA
Herding	0/10 (0%)	9/10 (90%)	3	2:35 s / 2:4 s / 2:42 s	ICM-PTT-LA
Deadlock	0/10 (0%)	10/10 (100%)	3	1:54 s / 2:44 s / 2:52 s	ICM-PTT-LA
Navigation Delay	0/10 (0%)	10/10 (100%)	3	2:15 / 2:22 s / 2:36 s	ICM-PTT-LA

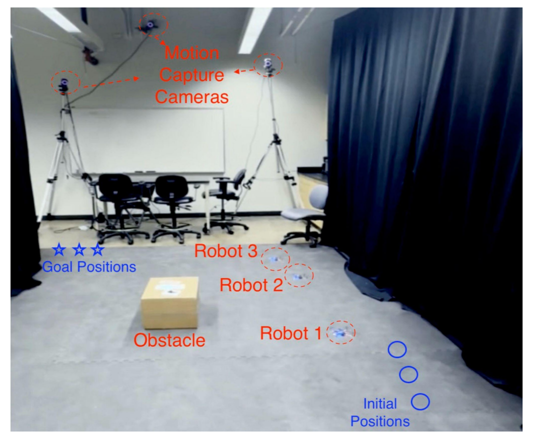
† HR: High Reactivity, ICM: Imperfect Communication and Measurements, PTT: Planning vs. Time Tradeoff, LA: Learning-based Algorithms, FC: Feasibility of Collisions.

- Successfully identified semantic attacks against ORCA and GLAS algorithms.
- Demonstrated stealthiness by evading anomaly detection mechanisms.
- Conducted experiments using high-fidelity simulator and Crazyflie drones demonstrating practicality of attacks.

Root Causes:

- High Reactivity
- Imperfect Communication
- Planning vs. Time Tradeoff
- Learning-based Flaws
- Feasibility of Collisions





Conclusion

- Discovered new semantic attack scenarios in multi-robot navigation.
- Introduced Raven framework to systematically uncover vulnerabilities.
- Identified key design flaws in widely adopted MRCA algorithms.
- Suggested robust countermeasures for enhancing system resilience.

Real-world End-to-end Demonstration

References

[1] Doguhan Yeke, Kartik A. Pant, Muslum Ozgur Ozmen, Hyungsub Kim, James M. Goppert, Inseok Hwang, Antonio Bianchi, and Z. Berkay Celik. Automated Discovery of Semantic Attacks in Multi-Robot Navigation Systems. Usenix Security 2025.

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